Profiles in Scientific Research

Contributions of the Fellows

VOLUME I

INDIAN NATIONAL SCIENCE ACADEMY
NEW DELHI

'Profiles in Scientific Research : Contributions of the Fellows' is a two-volume compilation consisting of articles on the research contributions of contemporary Fellows of the Indian National Science Academy in their own words. A list of chosen important publications of each author is appended. The entries, totalling 441, are arranged subject-wise in the following sequence :

Volume 1 : Mathematical Sciences, Physics, Chemical Sciences, Engineering & Technology, and Earth Sciences
Volume 2 : Plant Sciences, Animal Sciences, Medical Sciences, Biochemistry and Biophysics, Agricultural, Animal Husbandry, Fisheries and Forestry).

It is hoped that the publication will serve as an authoritative source-book of scientific achievements of leading Indian scientists. This venture of the Academy is also intended to provide material for the compilation of modern history of science in India.

(Cover design : Gopi Gajwani)

Indian National Science Academy,
Bahadur Shah Zafar Marg
New Delhi-110002.

Profiles in Scientific Research : Contributions of the Fellows

Profiles in Scientific Research : Contributions of the Fellows

VOLUME 1

(Mathematical Sciences, Physics, Chemical Sciences,
Engineering & Technology and Earth Sciences)

1986

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PREFACE

With the rapid strides being made in Science and Technology it is becoming increasingly difficult to have a proper appreciation of the contributions of fellow scientists. Fellows of the Academy would certainly be interested to learn about the research endeavours and accomplishments of the leading scientists in the country. The Academy has been publishing biographical memoirs of deceased Fellows, but there is a greater need for a document providing authentic accounts of the contributions of contemporary Fellows. The Council of the Academy agreed to the suggestion made by me to bring out the volume entitled 'Profiles in Scientific Research : Contributions of the Fellows'. Fellows were requested to write brief accounts of their work and choose 15 representative publications. This had a mixed reaction. Some Fellows were of the view that writing about themselves may be immodest. Others were somewhat surprised but recognised that it was worthwhile to make a statement on their work or on a certain area of science in which they have played a part. The response to our appeal has been overwhelming, and four hundred and forty one Fellows out of the total Fellowship of five hundred and thirty have indeed sent their contributions.

The publication is in two volumes and the contributions are arranged subject-wise. In order to retain the original flavour and style of the Fellows, minimum alterations have been made in the manuscripts. The Profiles would be periodically revised in the future and would become an important source book for research workers and provide material for compiling the history of science in India at a later stage.

The views expressed in these volumes are those of individual Fellows and not of the Academy. A few prominent scientists have not sent their entries. The value of this volume would have been greater if the entire Fellowship had been covered.

I thank all the Fellows who have spared their valuable time in preparing the entries. Special appreciation is extended to Professors S K Joshi and H Y Mohan Ram, Secretaries, for giving a concrete shape to the idea mooted by the Academy and to Shri R N Sharma, former Editor of the Publications and Information Directorate, Council of Scientific & Industrial Research, New Delhi, but for whose able and painstaking assistance, this publication would not have been completed in such a short time. I would like to make a special mention of the dedicated work done by Dr Alok Moitra of the Academy in processing the material and in seeing the publication through the press.

New Delhi
July 1986

C N R Rao
President
Indian National Science Academy

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Sectional Committee—I : Mathematical Sciences

(Applied Mathematics, Pure Mathematics and Statistics)

R P Bambah

Bambah was initiated into research by Prof. S Chowla in 1946, with whom he wrote several joint papers on congruence properties of Ramanujan function $\tau(n)$[1-3]. In 1947, Bambah and Chowla[4] used a straightforward construction to prove the existence of a constant C such that for $x \geqslant 1$ there is at least one integer between x and $x + Cx^{1/4}$, which can be expressed as a sum of two squares. They remarked that this is very far from the probable truth. But no essential improvement on this result has been obtained so far. Several authors [K N Majumdar (1950), S Uchiyama (1965), P H Diananda (1966) and L J Mordell (1969)] have worked on the value of C and/or generalization of this result.

Bambah wrote his PhD dissertation under the guidance of Prof. L J Mordell at Cambridge in 1950. He[5] developed a method for determining the critical determinant of non-convex star regions with hexagonal symmetry. He used this to obtain the critical determinant of several types of regions and, in particular, of the region $|f(x,y)| \leqslant 1$, where $f(x,y)$ is a binary cubic form of positive discriminant, which was originally obtained by Mordell.

Historically, the theory of packings and admissibility had attracted much more attention than the analogous concept of coverings. Bambah[6] developed the theory of coverings and answered several general questions about coverings, which are analogues of the corresponding results on critical determinants and packings. One of the important problems in the geometry of numbers is to determine the lattice covering density θ_n of the n-dimensional sphere. For circles, the result goes back to Dirichlet. Bambah[7] obtained θ_3 and later gave an estimate for θ_4 and conjectured its exact value. This conjecture was proved by B N Delone and S S Ryshkov (1963) and T J Dickson (1967). The first non-trivial bound for θ_n was obtained by Bambah and Davenport[8]. They proved that $\theta_n \geqslant \frac{4}{3} - \epsilon_n$, where $\epsilon_n \to 0$ as $n \to \infty$. This was later improved by Coxeter, Few and Rogers (1959).

A basic problem in the geometry of numbers is to determine whether the lattice covering density $\theta(K)$ of a given body K is equal to its general covering density $\theta^*(K)$. Kershner (1939) proved that this is so for a circle. Fejes Toth (1950) gave a proof of $\theta(K) = \theta^*(K)$, for two-dimensional symmetric convex domains. This proof was completed by Bambah and Rogers[9]. Simplified proofs of this result were given by Bambah, Rogers and Zassenhaus[10] and by Bambah and Woods[11]. In particular, they also showed that $\theta(C) = \theta^*(C) = \theta(K)$, for the

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cylinder C of height 1 with base K, which is a symmetric convex domain.

Stein (1972) proved that $\theta(S) = \theta^*(S)$ does not necessarily hold for star bodies. To prove this, he gave an example of a non-symmetric star body in five-dimensional space and a symmetric star body in ten-dimensional space. His examples had some other nice properties also. Bambah, Dumir and Hans-Gill[12] gave examples to show that there exist such star domains (symmetric and asymmetric) in the plane for which $\theta(S) \neq \theta^*(S)$. Another interesting and basic question is whether $\theta(K) = \theta^*(K)$ for the three-dimensional sphere K. Bambah and Woods[13] proved that double lattices do not give better coverings than the lattices for the three-dimensional spheres. The general question is still open.

Minkowski's second theorem involving the successive minima of a symmetric convex body w.r.t. a lattice is a generalization of his fundamental theorem. Proofs of this theorem had been given by Minkowski and Davenport (1939), Esterman (1946) and Weyl (1942). However, none of these was completely satisfactory. Bambah, Woods and Zaussenhaus[14] gave three proofs based on the earlier ones which are simpler and more satisfactory. These proofs have been used by Woods (1965) and Mcfeit (1969) to prove some generalizations.

One of the outstanding conjectures, attributed to Minkowski, is on the product of non-homogeneous real linear forms. Let $L_1, \ldots, L_n$ be n real linear forms in $x_1, \ldots, x_n$ of determinant $\Delta \neq 0$. Minkowski is believed to have conjectured that for any real numbers $c_1, \ldots, c_n$ there exist integers $x_1, \ldots, x_n$, such that

$$|(L_1 + c_1)| \ldots (L_n + c_n)| \leqslant |\Delta|/2^n.$$

The conjecture was proved by Minkowski himself for $n = 2$. Several proofs of this have since been given. For $n = 3$, it was proved by Remak (1923). A simpler proof was given by Davenport (1939). For $n = 4$, the first proof was given by Dyson (1948). A part of Dyson's proof borrows powerful tools from algebraic topology. Bambah and Woods[15] gave an elementary proof of Dyson's theorem, without using algebraic topology. A different proof of this result was given in Skubenko's papers in 1972, 1973 and 1976, which also dealt with the case $n = 5$. Following the general argument of Skubenko, a complete proof for $n = 5$ of Minkowski's conjecture was given by Bambah and Woods[16]. The problem remains open for $n \geqslant 6$.

Another basic problem in geometry of numbers is to determine $C_{r,s}$, the infimum of constants C, such that given any indefinite quadratic form $f(x_1, \ldots, x_n)$ of type (r,s) and determinant $D \neq 0$ and any real numbers $c_1, \ldots, c_n$, there exist integers $x_1, \ldots, x_n$, such that

$$|f(x_1 + c_1, \ldots, x_n + c_n)| \leqslant (C|D|)^{1/n}.$$

For $n = 2$, the result follows from Minkowski's theorem on the product of two non-homogeneous linear forms. Existence of $C_{r,s}$ was proved by Blaney (1948). Devenport (1948) determined $C_{1,2} = C_{2,1}$. Birch (1958) determined $C_{r,r}$ for all r. For $n = r + s \geqslant 21$, $C_{r,s}$ was determined by Watson (1962). He also conjectured the result for $n \geqslant 4$. Under his guidance and encouragement, the school developed by Bambah has succeeded in evaluating $C_{r,s}$ for signatures $\sigma = r - s = \pm 1, \pm 2, \pm 3, \pm 4$ and all values of n. In particular, $C_{r,s}$ has been obtained for $n \leqslant 6$. The conjectured values of $C_{r,s}$ depend on the residue class of the signature modules. In view of

Oppenheim's conjecture, it is very likely that the value of $C_{r,s}$ for all values of σ would follow from the above result.

The analogous problem for the positive values of non-homogeneous indefinite quadratic forms has also been studied for quite some time. Let $\Gamma_{r,s}$ denote the infimum of all constants Γ (existence of which follows from Blaney (1948) for which the inequality

$$0 < f(x_1 + c_1, \ldots, x_n + c_n) \leqslant (\Gamma |D|)^{1/n}$$

has a solution in integers $x_1, \ldots, x_n$ for all real numbers $c_1, \ldots, c_n$ and all indefinite quadratic forms $f(x_1, \ldots, x_n)$ of type (r,s) of determinant D. The problem is to determine $\Gamma_{r,s}$. Davenport and Heilbronn (1947) obtained $\Gamma_{1,1}$. $\Gamma_{2,1}$ was obtained independently by Blaney (1952) and Barnes (1962). Bambah[17,18] and his school have determined $\Gamma_{1,3}$ and $\Gamma_{r,s}$ for signatures $\sigma = r - s = 0, \pm 1,2,3$ and for all values of n. Some isolation results and several other asymmetric results have also been obtained either for the purposes of applications to the above problems or for their independent interest.

Bambah has also obtained several other results, contributing to non-homogeneous minima of special binary forms, polar reciprocal convex bodies, divided cell, transference theorems, lower bounds for minimum distance codes, convex bodies with covering property and many other topics in discrete geometry.

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2. Bambah R P & Chowla S, The residue of Ramanujan's function $\tau(n)$ to the modulus 2^8, *J Lond math Soc*, **22** (1947) 140-47.
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5. Bambah R P, On the geometry of numbers of non-convex star regions with hexagonal symmetry, *Phil Trans R Soc*, **243** (1951) 431-62.
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12. Bambah R P, Dumir V C & Hans-Gill R J, Covering by star domains, *Indian J pure appl Math*, **8** (1977) 344-50.
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16. Bambah R P & Woods A C, Minkowski's conjecture for $n = 5$; a theorem of Skubenko, *J Number Theory*, **12** (1980) 27-48.
17. Bambah R P, Dumir V C & Hans-Gill R J, Positive values of non-homogeneous indefinite quadratic forms, Proc. Colloquim Mathematica Societatis Janos Bolyai 34, Topics, in *Classical Number Theory* (North Holland, Budapest, Hungary), 1981.
18. Bambah R P, Dumir V C & Hans-Gill R J, Positive values of non-homogeneous indefinite quadratic forms II, *J Number Theory*, **18** (1984) 313-41.

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S K Chakrabarty

Cosmic rays are being continuously received on the surface of the earth from outer space. Their multiplication and absorption in passing through our atmosphere, as well as through different solid and liquid materials, therefore, should give information about the origin of cosmic rays, their multiplication and absorption in different materials, and our atmosphere. This information is also useful in the study of atomic processes, particularly in the energy ranges which are not available through laboratory methods.

Some aspects of solar surface, viz. the 'sunspots' and their relations with the activities of the 'chromospheric eruptions', are visible from the earth, and their effects are recorded. Analyses of the 'geomagnetic field' and its time variations, both regular and irregular, as recorded at observatories on the surface of the earth, therefore, provide useful informations about the structure of the upper atmosphere, ionosphere and that of the solar surface.

The structure of the earth from the surface to its centre is studied through analyses of the records of natural earthquakes and also of artificial earthquakes. For precise measurements and analyses of the records of such earthquakes, highly sensitive seismographs and geophones are required and precise estimates of their 'response characteristics' are to be made, which may then provide useful informations relating to the structure of the interior of the earth, from the surface to its centre. Precise information on these aspects is essential for economic exploitation of underground oils, minerals and water, and also for economic designs of tall structures, particularly in and around seismic zones.

A brief account of some original contributions of S K Chakrabarty and his coworkers since 1936 on the problems referred to above is given here.

While working on some discrete problems of Quantum Mechanics, in 1940 Chakrabarty got interested in the development of 'cosmic ray showers' through the 'cascade process'. Following the physical ideas put forward by Bhabha and Heitler and also by Carlson and Oppenheimer, Bhabha and Chakrabarty put forward an elegant and rigorous analysis for the accurate estimation of 'shower particles and quanta' at different depths, produced by an electron and a photon, in passing through solid materials or atmosphere, making a more rigorous treatment of the problem, from the standpoints of both physical assumptions and mathematical treatments. Preliminary results taking the 'radiation' and 'pair-creation' cross-sections, valid in the case of 'complete screening', as suggested by Bethe and Heitler, and neglecting 'collision

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loss' entirely, the 'cascade process' was worked out by Chakrabarty[1] in 1942. It was shown that the total number of particles $N(E,t)$ at depth t and having energies greater than E, produced by a primary particle of energy E_0 is given exactly in a closed form by

$$N(E,t) = \frac{1}{2\pi i} \int_{\sigma - i\infty}^{\sigma + i\infty} \left(\frac{E_0}{E}\right)^{s-1} \cdot \frac{1}{s-1} \times \left\{ \frac{D-\lambda}{\mu-\lambda} e^{-\lambda t} + \frac{\mu - D}{\mu - \lambda} e^{-\mu t} \right\} ds \quad \ldots (1)$$

and the corresponding energy spectra for particles and quanta were given by:

$$P(E,t) = \frac{1}{2\pi i E_0} \int_{\sigma - i\infty}^{\sigma + i\infty} \left(\frac{E_0}{E}\right)^{s} \times \left\{ \frac{D-\lambda}{\mu-\lambda} e^{-\lambda t} + \frac{\mu - D}{\mu - \lambda} e^{-\mu t} \right\} ds$$

$$Q(E,t) = \frac{1}{2\pi i E_0} \int_{\sigma - i\infty}^{\sigma + i\infty} \left(\frac{E_0}{E}\right)^{s} \times \frac{C}{\mu-\lambda} \{e^{-\lambda t} - e^{-\mu t}\} ds \quad \ldots (2)$$

where A_s, B_s, C_s, λ and μ are some functions of s, defined in the paper referred to above[1], and D is a material constant. The integrals were evaluated using 'saddle point' method, and the values of $N(E,t)$, $P(E,t)$ and $Q(E,t)$ were obtained with an error less than 2%. Some results were given by Chakrabarty[1] in tabular forms and also by graphs. However, collision loss in the process of 'cascade' formation, while passing through dense material, produces a significant impact and cannot be neglected. Bhabha and Heitler introduced the concept of 'critical energy', at which an electron suffers equal energy loss through the processes of 'radiation' and 'collision' and assumed that the collision loss would not affect the cascade process above the 'critical energy'. As such, the effect of 'collision loss' was not treated quantitatively. In consequence, the results were only approximate and could not be used for any quantitative analyses.

In a series of investigations, Bhabha and Chakrabarty[2-4] studied the effect of 'collision loss' and derived solutions for the 'cascade equations', which may be used for estimating the energy distribution of the 'shower particles and photons' of all energies, including those near and even below the 'critical' energy. It was shown[4] that the energy spectra of the 'cascade particles' given by $P(E,t)$ and the total number of 'shower' particles, $N(E,t)$ at any depth t, in 'radiation units', produced by a primary particle of energy E_0 are given by:

$$P(E,t) = \frac{1}{2\pi i E_0} \int_{\sigma - i\infty}^{\sigma + i\infty} \left(\frac{E_0}{E + \beta g}\right)^{s} \times \left\{ \sum_{n=0}^{\infty} \left(\frac{\beta}{E+\beta g}\right)^{n} \frac{\Gamma(s+n)}{\Gamma(s)} f_n(s,t) \right\} ds$$

$$N(E,t) = \frac{1}{2\pi i} \int_{\sigma - i\infty}^{\sigma + i\infty} \left(\frac{E_0}{E + \beta g}\right)^{s-1} \frac{1}{s-1} \times \left\{ \sum_{n=0}^{\infty} \left(\frac{\beta}{E+\beta g}\right)^{n} \frac{\Gamma(s+n)}{\Gamma(s)} f_n(s,t) \right\} ds \quad \ldots (3)$$

where $f_n(s,t)$, $g(s,t)$ and $\Psi(s,t)$ have been defined. Numerical values for $g(s,t)$, $P(E,t)$, and $N(E,t)$, for different values of g, s, E_0, E and t, have been given by Bhabha and Chakrabarty[4], together with an estimate of the rapidity of convergence of the series solutions. Applications of these results to the solution of different problems were also indicated[8].

In later papers[5,7], Chakrabarty and Gupta showed that the solution of the cascade equations derived earlier[4] can by applying a Laplace transformation in t be put in the form:

$$P(E,t) = \sum_{m=0}^{\infty} P_m(E,t) \qquad \ldots (4)$$

where

$$P_m(E,t) = \frac{1}{2\pi i\beta} \int_{\sigma-i\infty}^{\sigma+i\infty} ds \left(\frac{E_0}{\beta}\right)^{s-1} \frac{1}{2\pi i} \int_{\gamma-i\infty}^{\gamma+i\infty} dp \frac{\Gamma(s+p)\,\Gamma(-p)}{\Gamma(s)} \left(\frac{\beta}{E}\right)^{s+p} \times \left[\frac{D-\lambda_{s+m}}{\mu_{s+m}-\lambda_{s+m}}\right] \exp(-\lambda s + m^t) \times G_m(s,p) + \frac{\mu_{s+m}-D}{\mu_{s+m}-\lambda_{s+m}} \exp(-\mu_{s+m}t)\, F_m(s,p) \qquad \ldots (5)$$

and σ is such that when $R(s) > \sigma$, the integrand is analytic and for $-1 < R(\gamma) < 0$, $G_m(s,p)$ and $F_m(s,p)$ are functions of s, p and m, given by :

$$G_m(s,p) = \Gamma(p+1) \lim_{N\to\infty} \left\{\psi_0(S+N+1, -\lambda_{s+m})\right\}^{p+1} \times \prod_{\substack{i=0\\ \neq m}}^{N} \psi_0(s+i, -\lambda_{s+m}) \times \prod_{i=0}^{N} \frac{1}{\psi_0(s+p+i+1, -\lambda_{s+m})}$$

and

$$F_m(s,p) = \Gamma(p+t) \lim_{N\to\infty} \{\psi_0(s+N+1, -\mu_{s+m})\}^{p+1} \prod_{\substack{i=0\\ \neq m}}^{N} \psi_0(s+i, -\mu_{s+m}) \prod_{i=0}^{N} \frac{1}{\psi_0(s+p+i+1, -\mu_{s+m})} \qquad \ldots (6)$$

where

$$\psi_0(s,r) = \int_0^{\infty} e^{-rt}\, \psi_0(s+t)\, dt = \frac{D+r}{(r+\lambda_s)(r+\mu_s)}$$

Similar forms for $P(E,t)$ and $N(E,t)$ were given earlier by Chakrabarty[6].

It is evident from the above that $G_m(s,p)$ and $F_m(s,p)$ are smooth functions of s and p for each value of m, provided only that $R(s+p) > 0$. Although the right side of Eq. (4) is in the form of an infinite series, P_0 alone gives practically the entire contribution. It is easy to calculate the subsequent terms in the series, and it has been verified that even P_4 in Eq. (4) makes a contribution which is less than 1% of P_0. The values of the subsequent terms are, however, much less. We can thus take $P(E,t) \approx P_0(E,t)$, and in a similar way,

$$N(E,t) \approx N_0(E,t) \approx \frac{1}{2\pi i} \int ds \left(\frac{E_0}{\beta}\right)^{s-1} \frac{1}{2\pi i} \int \frac{\Gamma(s+p-1)\,\Gamma(-p)}{\Gamma(s)} \times \left(\frac{\beta}{t}\right)^{s+p-1} \times e^{-\lambda_s t}\, G_0(s,p)\, dp \qquad \ldots (7)$$

The term containing $e^{-\mu s t}$ makes a contribution only when t is very small, as shown in the earlier papers[3,4] and even for $t \geqslant 0.5$, its contribution can be neglected. The values of $P_m(E,t)$ and $N_m(E,t)$ for different values of E_0, E and t have been calculated using the 'saddle point method' and the results are given by Chakrabarty and Gupta[5]. The 'saddle point' in the evaluation of $P(E,t)$ and $N(E,t)$ lies within two extreme values, viz. $(s + p) \rightarrow 0$ and $(-p) \rightarrow 0$, which correspond to the cases when $E \rightarrow 0$ and $E \rightarrow \infty$ respectively.

The values of $\log_e G_0(s,p)$ and $N_0(E,t)$ have been given by Chakrabarty and Gupta[5]. It has been shown there (Eq. 20) that $N_0(0,t)$ is equal to $[e/(2\pi)^{1/2}]$ $G_0(s_0^0 - s_0^0 + 1)$. $N_\lambda\ (\beta,t)$. The values of $N(E,t)$ and $P(E,t)$ obtained by Snyder [*Phys Rev*, **76** (1949) 1563] are thus valid only when $E \rightarrow 0$.

Some values of $N(E,t)$ for different values of E_σ, E, and t are given in the paper of Chakrabarty and Gupta[5] and others as may be required can be easily calculated by the methods described using the relevant tables given there, and also those quoted by Janossy [*Cosmic rays* (Clarendon Press, Oxford) 1948, 222-23, 263, 303, 391-98].

Early in 1945, Chakrabarty joined the India Meteorological Department, as Director of the Geophysical Observatories at Colaba and Alibag (Bombay) and became interested in geomagnetism and seismology.

By analysing a long series of geomagnetic records of the Alibag Magnetic Observatory, and using the solar data of the Kodaikanal Observatory, it was shown by Chakrabarty[9] that a narrow beam of solar corpuscles emitted from a point on the surface of the sun produced 'magnetic storms', which were simultaneously recorded at different magnetic observatories on the surface of the earth, the duration of the storms being dependent on the width of the velocity spectrum of the emitted particles, which are of the order of 10^8 cm per sec, as suggested by Milne. Every 'big' magnetic storm was associated with a 'chromospheric eruption' occurring in the neighbourhood of an active sunspot; the duration of each 'storm' recorded simultaneously at different observatories was nearly equal, and depended on the width of the velocity spectrum of the emitted particles. While most of the big 'storms' are of the 'sudden commencement type', the nature and intensity of their 'commencement' depended on the latitude and longitude of the observatory, as shown[10] from an analysis of nearly 800 storms recorded at the Alibag Magnetic Observatory during 1905 to 1944, and do not follow a standard pattern. Typical 'micropulsations' were also recorded at Alibag, but all of them were not recorded simultaneously like 'storms' in different magnetic observatories of the Earth.

Chakrabarty and Pratap[11] analysed the diurnal S_Q variations at Alibag on several IQ days and fitted them with the results of calculations based on the 'Dynamo theory' with some assumed 'ionospheric conductivity' and 'atmospheric oscillations'.

From the different analyses described above, it is possible to get a reasonable picture about the (a) solar chromospheric eruptions, (b) sunspot activities, (c) ionospheric conductivity, and (d) atmospheric oscillations, along with their seasonal variations, which may well be compared with relevant data obtained from observations through satellites.

In 1948, Chakrabarty joined the Seismological Laboratory of the California Institute of Technology, Pasadena, USA, and had the opportunity of working with a group of eminent seismologists under the leadership of Prof. B Gutenberg. In collaboration with C F Richter, Chakrabarty[12] analysed the records of the Walker Pass earthquakes of 15 March 1946, which had a large 'foreshock' and a number of 'aftershocks', recorded at Pasadena and also at a large number of auxiliary stations. The analyses giving the 'epicentre' of the 'principal shock' and of the large number of 'aftershocks' and their 'origin times' led to a precise determination of the underground structure of the region. The effects of the 'roots' of the neighbouring mountains were also observed.

Chakrabarty[13] started his works on the response characteristics of electromagnetic seismographs and their precise estimations through experiments carried out in collaboration with Dr Benioff, at the Seismological Laboratory, Pasadena in 1948. The response of a seismograph subjected to a simple harmonic ground motion was recorded and compared with the analytical expression for the response of the seismograph. In a series of papers, Chakrabarty and his coworkers developed in details methods for estimating precisely the instrumental constants of the electromagnetic seismographs[14], the methods of their calibration[15], and also variation of their 'magnification' with changes in 'damping' and 'reaction'[16]. The variation of 'magnification' with change in 'damping', 'periods', and 'reaction' of the seismographs, as are in existence in different observatories, have been worked out[17], to cover the possible changes in the instrumental constants. These results and graphs can be used for precise estimation of the instrumental constants without disturbing their operating conditions.

A summary of some of these works was incorporated in the UNESCO publication entitled 'Manual of Seismological Observatory Practice', prepared by the International Committee for the Standardization of Seismographs and Seismograms, appointed as a consequence of a resolution of UNESCO. The committee was appointed by the President of the International Association of Seismology and Physics of the Earth's Interior. Chakrabarty represented India in the Committee. The Committee first met in Paris during 12-15 March 1963. After detailed discussions, the responsibilities for drawing up the section on 'Instruments and Their Choice, Adjustments and Calibration' were entrusted to Chakrabarty (India), Dr Grenet (France), and Prof. J T Wilson (USA). The report was published by UNESCO in 1967, as a reference manual, and was made available to different seismological observatories of the world.

Studies on the structure of the earth's interior are important from the academic point of view as well as for the economic exploitation of underground minerals, oils and water. The structure of the earth's interior from its surface to its centre can be determined by studying the records of earthquakes, both natural and artificial, and for these purposes different types of seismographs and geophones are now being used; their response characteristics are estimated precisely through well designed experiments referred to above.

Useful records of microseisms[18] associated with cyclones and norwesters are also recorded in the coastal regions of the Bay of Bengal and of the Arabian Sea. These help in the forecasting of probable cyclones and also in the approximate determination of the structure of the sea bed, particularly in the neighbourhood of the continental shelves.

The mechanism and intensity of the force system at the hypocentre have been studied through recorded displacements at different locations on the surface of the earth, which are also dependent on the structure of the medium through which the seismic waves travel from the hypocentre to the surface. In an approximate way, the medium may be assumed to be multilayered and composed of solid and liquid materials. The analyses presented[19] can be used to obtain quantitative estimates of the mechanisms at the hypocentre, and also for studying the structure of the different layers of the earth from its surface to the centre. These results can also be used in a more precise manner for the exploration of oils and minerals within the earth's crust[20], and also for obtaining useful information about the structure of the core of the Earth[21].

Selected Publications

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

V C Dumir

Dumir started his research career under the guidance of Prof. R P Bambah at Punjab University, Chandigarh in 1962. He took his PhD degree from Ohio State University, Columbus, Ohio in 1965 under Prof. Bambah in the field of geometry of numbers.

One of the basic problems in geometry of numbers is to determine $C_{r,s}$, the infimum of the constants C, such that given an indefinite quadratic form $Q(x_1, \ldots, x_n)$ of type (r,s) and determinant $D \neq 0$ and any real numbers $C_1, \ldots, C_n$, there exist integers $x_1, \ldots, x_n$, such that

$$Q(x_1 + c_1, \ldots, x_n + c_n) \leqslant (C \leqslant D)^{1/n}$$

For $n = 2$, $C_{1,1} = \frac{1}{4}$ follows from Minkowski's theorem on the product of two non-homogeneous linear forms. Existence of $C_{r,s}$ was proved by Blaney (1948). Davenport (1948) determined $C_{1,2} = C_{2,1}$. Birch (1958) determined $C_{r,r}$ for all r. For $n = r + s \geqslant 21$, $C_{r,s}$ was determined by G L Watson (1962). He conjectured his result to be true for $n \geqslant 4$. Dumir[1] proved Watson's conjecture for $n = 4$ by proving that $C_{3,1} = C_{1,3} = \frac{1}{3}$. ($C_{2,2} = \frac{1}{4}$ follows from Birch). Recently, the conjecture has been proved by Madhu Raka for signatures $\sigma = r - s = \pm 1, \pm 2, \pm 3, \pm 4$, and for all n. Since the conjectured values of $C_{r,s}$ depend on the residue class of the signature σ(med 8), it is very likely that the conjectured values for all σ will follow from the above result.

The analogous problem for the positive values of non-homogeneous indefinite quadratic forms is as follows. Let $\Gamma_{r,s}$ denote the infimum of the constants Γ such that given any indefinite quadratic form $Q(x_1, \ldots, x_n)$ of type (r,s), determinant $D \neq 0$ and any real numbers $c_1, \ldots, c_n$, there exist integers $(x_1, \ldots, x_n)$ such that

$$0 < Q(x_1 + c_1, \ldots, x_n + c_n) \leqslant (\Gamma |D|)^{1/n}.$$

Davenport and Heilbronn (1947) determined $\Gamma_{1,1}$. $\Gamma_{2,1}$ was obtained independently by Blaney (1952) and Barnes (1961). Dumir[2–4] determined $\Gamma_{1,2}$, $\Gamma_{3,1}$, $\Gamma_{2,1}$. $\Gamma_{1,3}$ was determined by Dumir and Hans-Gill[5] in 1981. $\Gamma_{4,1}$ and $\Gamma_{3,2}$ have been determined by Hans-Gill and Madhu Raka. Recently, Bambah, Dumir and Hans-Hill[6–8] have determined $\Gamma_{r,s}$ for signatures $\sigma = 0, \pm 1, 2$ and 3 for all n. In particular, they showed that $\Gamma_{2,3}$ is isolated and obtained the first two minima. Dumir and Hans-Gill (unpublished) have also shown that $\Gamma_{1,2}$ is isolated and obtained the second minima. Dumir[9] also studied the asymmetric problem for the non-homogeneous ternary forms of the type

$$-t(f(t)|D|)^{1/3} < Q(x_1 + c_1, x_2 + c_2, x_3 + c_3) \leqslant (f(t)|D|)^{1/3}.$$

Bambah, Dumir and Hans-Gill have obtained several other asymmetric results

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either for the purpose of applications to the above problems or for their independent interest.

Dumir and Khassa[10] proved a conjecture of Fejes Toth on the saturated systems of circles and showed[11] that a corresponding result also holds for symmetric convex domains. Partial results in this direction were earlier proved by L Fejes Toth, Eggleston, Bambah and Woods.

Dumir and Hans-Gill[12,13] also considered the problem of lattice double packing density $\delta_2(k)$ and the lattice double covering density $\theta_2(k)$ in the plane and showed that $\delta_2(k) = 2\delta(k)$, $\theta_2(k) = 2\theta(k)$ for symmetric convex domains K, but the result is false for star domains.

One of the problems is whether $\theta(s) = \theta^*(s)$, where $\theta(s)$ denotes the lattice convering density of S and $\theta^*(s)$ is the general covering density of S. Stein (1972) had given an example of a symmetric star body in R_{10} and a non-symmetric star body in R_5 for which $\theta(s) \neq \theta^*(s)$. Bambah, Dumir and Hans-Gill[14] gave examples of star domains in R_2 the plane for which $\theta^*(s) \neq \theta(s)$.

Recently, Dumir and Hans-Gill[15] have proved a conjecture of Cusick on view obstruction problem for spheres in $\mathbb{R}_3$ and showed that the result is isolated and have obtained an infinite sequence of isolated minima converging to $1/\sqrt{3}$.

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*The numbers within square brackets at the end of some references denote the review number in *Mathematical Reviews*.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

J K Ghosh

Ghosh's work is primarily in inference. The limit theorems he has proved were all motivated by problems in inference. Though the work in modelling is not intimately connected with inference, at least one limit theorem of inferential origin finds application here. His early papers were mostly on sequential analysis, sufficiency and invariance and the later ones mostly on identifiability, higher order efficiency, related limit theorems and modelling. A partly chronological and partly subject-wise description follows.

Ghosh published some important papers in sequential analysis[1–4]. He showed[4] that if a problem is left invariant by a group of transformations which also act on a sufficient sub σ-field, then the maximal invariant sub σ-field of the sufficient sub σ-field is sufficient for the invariant σ-field of the original problem. He also showed[1] that every GSPRT (generalized sequential probability ratio test) is unbiased, leading to the monotonicity of the error probability of GSPRT's under an assumption of motonone likelihood ratio. These two results still provide the most convenient way of constructing sequential tests of composite hypotheses. Recently, Ghosh and A Raychaudhuri have used results from an earlier paper[4] for the solution of classification problems based on sequential samples; the result in another paper[1] had to be replaced by a new inequality. In one of the papers[3], various Bayes rules for multiple decision problems are shown to be natural extensions of GSPRT's; applications include the so-called Kiefer-Weiss problem of minimizing the (maximum) expected sample size given restrictions on the error probabilities.

Ghosh and coworkers published several papers[4–8] on sufficiency and invariance. In one of these[5], the minimal sufficient σ-field was shown to exist and was identified for all discrete problems, including sample surveys, settling an old problem. This had been a problem because such families of probability measures are not dominated by σ-finite measures. In another paper[8], various questions connected with sufficiency are posed and explored when the family of probability measures is dominated by a non σ-finite but localizable measure (as in the discrete case). In the work done during the sixties, Ghosh also showed that if $X_1, \ldots, X_n$ are i.i.d. and the family of probability measures is dominated by a σ-finite measure, then (marginal) sufficiency for each X_i implies sufficiency for $X_1, \ldots, X_n$, settling a problem due to Huzurbazar. In one paper[7], it was shown that if X is normal with mean μ and variance σ^2, and T is a real valued measureable function, such that $T(X)$ is also normal, then T must be linear almost everywhere, provided μ

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takes at least two distinct values and σ^2 takes all positive values. The best result of this type is still not known, but the condition on μ can be relaxed. In the paper coauthored with Basu[6], there is a measure P and a group G (usually the translation group) and one wants to know whether there are non-trivial sets A, such that $P(gA) = P(A)$ for all $g \in G$, whether such sets form a σ-field and so on. Partial results were obtained; some of the problems posed there were later solved by Blum, Pathak and Rickert.

Ghosh's main interest in recent years has been higher order efficiency, which has its roots in a cryptic remark of Fisher 60 years ago. The first clarification came in three papers of C R Rao published in the early sixties. The final definitive results were obtained during the last 10 years, the main contributors being Akahira, Bickel, Efron, Ghosh, Pfanzagl, Takeuchi and Van Zwet. In Ghosh's work, the general problem is posed for the first time and partly solved; in another paper[10], a complete proof is given for all natural loss functions and the so-called continuous cases and partly in still another paper[11], where the condition on continuity is relaxed. (In the latter paper[11], the loss is squared error, but it can be relaxed to cover all natural loss functions.) Roughly speaking, the results proved may be summarized as follows: Given an asymptotically efficient estimate T_n based on n i.i.d. observations $X_1, \ldots, X_n$, one can find a function $c(.)$ such that $\theta^* = \hat{\theta} + c(\hat{\theta})/n$ is better than T_n in the sense that

$$E_\theta \{l\sqrt{n}\ (T_n - \theta)]\} \geqslant E_\theta \{l[\sqrt{n}(\theta^* - \theta)] + o(n^{-1})\},$$

where $\hat{\theta}$ is the maximum likelihood estimate (or rather a consistent solution of the likelihood equation) and $\ell(x)$ is any bounded continuous symmetric function which is monotone in $|x|$. Here, $c(.)$ is easy to find and does not depend on $\ell(.)$. This shows that in a certain sense, $\hat{\theta}$ behaves like a sufficient statistic up to a third degree of approximation. (Some workers, e.g. Ghosh and Rao, call this a second degree approximation, but it is now clear from the point of view of Edgeworth expansions that third is the right adjective. Depending on this, one calls this property of $\hat{\theta}$ second order efficiency or third order efficiency.) It is also true that, roughly speaking, estimates of the type $\hat{\theta} + c(\hat{\theta})/n$ form a complete class in the decision theoretic sense. Even though such a result does not solve the practical problem of choice of estimates as the classical result on first order efficiency does (to a first order of approximation), it does simplify the problem enormously; some evidence of this is available in the work done by Ghosh and Sinha, but much more needs to be done.

Ghosh's earliest work in limit theorems provides an extremely simple non-computational proof of what is called Bahadur representation of quantiles. His later work with Bhattacharya[12] settles an old conjecture on Edgeworth expansions. The need for these results came from the work of Ghosh and coworkers[9,10], but they are useful in many other contexts. Among other things, they generalize results of P L Hsu and K L Chung on refinements of the central limit theorem for many classical moment statistics. A similar result was obtained by Ghosh and Chandra[13] for likelihood ratio statistics; such expansions have been used informally for more than 30 years, but rigorous justification had been out of bounds. Approximation to Bayes risk, Bayes estimates and posteriors is provided in the paper of Ghosh, Sinha and Joshi[11]. Its applications include higher order efficiency and sequential estimation. These approximations are essentially refinements of the Bernstein-von Mises theorem on the asymptotic normality of posteriors, but studied under the prior, not a fixed θ, and hence rather delicate. For example, it is shown that such refinements are not possible for a uniform prior distribution.

Ghosh's work on modelling has been confined to problems in sediment transport and statistical quality control. In the first field, Ghosh and coworkers[14] have set up a model based on diffusion process with a reflecting boundary. They tried to explain log normality of sediment distributions in experiments by a sorting phenomenon, which is mathematically very similar to the approximate normality of posteriors; this is quite different from explanations based on the central limit theorem. In a recent work [*J sediment Petrol* (1986), in press], they also consider models for deposition with different boundary conditions that give better fit to data. In statistical quality control, Ghosh and Dasgupta developed a model for cutting processes by a sequence T_n defined recursively as $T_n = T_{n-1} + c_n \ (X_n - T_{n-1})^+$, where $0 \leqslant c_i \leqslant 1$ is a sequence of positive constants; X_i's are i.i.d.; and $X^+ = \max\ (X, 0)$. Under some additional conditions, they studied its limiting behaviour; there are still many open questions in this area.

It had long been believed by statisticians that confidence intervals shortest in the sense of Neyman have no relationship to those which minimize the average length. Ghosh[2] had shown that the former property implies the latter; the same result was obtained by Pratt at the same time. In a paper of Ghosh and Basu[15] it is shown that if (X, Y) and (U, V) are each bivariate normal with the same distribution for Min (X, Y) and Min (U, V), then X and Y have the same covariance as U and V with means and variances either same or a permutation of one another; the proof uses a classical result of Liouville that the normal distribution function is not an elementary function. This identifiability result has already had applications in the theory of competing risks.

In the next few years, Ghosh hopes to concentrate on inference problems where the number of nuisance parameters is of the same order of magnitude as the sample size. Ghosh also hopes to work on theoretical problems arising from current data analytic techniques such as cluster analysis; a recent study of likelihood ratio test for mixtures will appear in the proceedings of the Berkeley conference held in honour of Neyman and Kiefer. It takes the first step in showing what modifications are needed in the classical theory if identifiability is absent.

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N L Ghosh

Ghosh's contributions run in three streams: (1) The theory of equilibrium of rotating fluids under self-gravitation. (2) The theory of viscous fluids, in particular, Resistance in Real Fluid flows. (3) A new approach to the mechanics of a continuous medium.

(1) Equilibrium of Rotating Fluids under Self-Gravitation

The explanation of the spheroidal form of the planets and various astral bodies attracted the attention of the physicists and mathematicians not very long after Newton's theory of gravitation was established firmly. After McLaurin obtained his solution for a homogeneous liquid in 1934, no solution was obtained though all the stalwarts of Europe tried their hands. Dive succeeded in 1930 in proving the negative result that equilibrium in spheroidal form is not possible if the pressure is a function of the density only.

Ghosh in 1948, having obtained a simple and direct proof of the celebrated 'Hamy's theorem', turned his attention to the above problem (without knowledge of Dive's results in a French text) and succeeded independently in arriving at all the results of Dive by an entirely different method. He also succeeded in constructing two models demonstrating the equilibrium, with a variable angular velocity and density, under stratifications either similar to or confocal with the spheroidal boundary $1 - \alpha t^2 - \beta z^2 = 0$, r and z being the cylindrical co-ordinates of a point on the boundary.

In all 11 papers were published on the subject.

Case (A) : Similar stratification : The main features of this study reported in a paper[1] were as follows:

(i) The pressure p at any point is of the form $p = K\rho^2 + K'\rho^3\ (1 - mr^2)$, where K, K', m are constants and $m \leqslant \alpha$, so that $p \neq p(\rho)$.

(ii) The angular velocity ω inside is given by a simple quadratic in r and z, $\omega^2 = c_1\rho + c_2 + c_3\ r^2$, where c_1, c_2, c_3 are finite constants satisfying all requirements of the physical equilibrium.

(iii) A study of the secular variable $\omega'/2\pi\rho$ (bar indicating the average values) leads to the very interesting cosmological result that the model, starting as an infinite sphere of vanishing density, can ultimately reduce itself to the flat plate configuration of a finite equitarial extension.

Case (B) : Confocal stratification : This study led to the following conclusions:

(i) Equilibrium is possible under any law of confocal stratification and the general

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forms of ω, ρ and p are obtained in simple elegant forms.

(ii) Shells of equal density rotate as a whole, the angular velocity diminishing outwards.

(iii) A model with the density distribution $\rho=\rho_0\left(1-\frac{mG}{(1+G^2)^{1/2}}\right)$ (where m, ρ are constants and $m > 1$) is obtained showing the interesting property that with the loss of energy by radiation and the consequent increase in ω (as in the previous case), the model contracts in equitorial extension and starting from a flat plate form, it ultimately reduces to a sperical point mass of extremely high angular velocity and density.

From the above it became clear that the whole range of cosmological models from an infinite sphere of vanishing density to a flat disc of a finite radius and then from flat disc of finite radius down to a point mass of a very high density and angular velocity, is covered by the two models.

Case (C) : Anchoring configuration : This work[3] showed that the anchoring has an elliptic section with extremely elegant and simple expression for all the quantities p, ρ, ω and the ring can reduce to a flat plate (with the heavy body at its centre), exactly like what is actually seen in photographs of Saturn's ring. It also comes out that a thin atmosphere around a heavy central core can with increasing rotation flatten and ultimately detach itself as the ring.

Case (D) : Equitorial acceleration : The models discussed in cases (A) and (B) both show "Equatorial retardations", i.e. the surface angular velocity increases from the equator to the pole. But the observations on Sun, Jupiter and Saturn and some other bodies show the opposite phenomenon, the surface rotations decreasing from the equator to the pole. This phenomenon, known as "Equatorial acceleration", has been known since 1860, but some scientists of repute tried to explain this away as the braking effect of the atmosphere. So, it received no attention till Ghosh was able to construct a model with a quadratic law of distribution of density $\rho = \rho_0\ (1 - \lambda\alpha r^2 - \mu\beta x^2)$ and the boundary $1 - \alpha r^2 - \beta x^2 = 0$. The potential being obtained in an ingenious way, the solution for the surface angular velocity was obtained in a closed and neat form, the existence of equatorial acceleration being ensured by the condition $0 \leqslant \lambda < \mu \leqslant 1$. The solution covers all the previous cases also. In physical terms, it means that when the equi-density surfaces, which are all spheroids, are flatter than the boundary, the model shows equatorial acceleration; otherwise it shows equatorial retardation.

Faye's formula constructed to explain the observed surface angular velocity of the Sun agrees with Ghosh's results[4].

(2) Theory of Resistance in Real Fluids

In 1952, while working as Senior Research Fellow of the National Institute of Sciences of India, Ghosh took up the study of viscous fluids. He noted that the central problem was the problem of resistance, but the prevailing theories (for attacking the problem) were full of contradictions, complexities and paradoxes. Ghosh proposed a new theory of resistance in real fluid flows[5]. He showed that all the difficulties and complexities of the problem will disappear if only it is recognized that:

(i) A real fluid like air or water has an appreciable viscosity and cannot be treated as a perfect fluid. The stress at any point, therefore, has all the six components and as such the thrust on any surface has both a normal and a tangential component p_n and p_t and not merely the isotropic scalar p of hydrodynamics.

(ii) When a real fluid flows past a body, the tangential or the frictional component must be directed opposite to the sense of relative motion.

(iii) The flow past is essentially a 'potential flow' slipping past an indefinitely thin layer of fluid sticking on the body surface, forming Prandtl's ideal boundary layer and the discontinuous velocity layer generating the vorticity on the body surface.

Based on the above premises, the whole theory is now a purely deductive system for the determination of resistance and other parameters.

There are two types of flows: A flow without a wake—we have called such a flow as 'primary flow'—and a flow with a 'vortex wake'.

Primary flows : It has been possible to evaluate in exact and finite terms the resistance in primary flows past spheres, spheroids and in fact any axisymmetrical body[6].

The flow past a circular cylinder with a circulation was transformed into the flow past an aerofoil by the Jukowski transformation. This led to the determination of the lift and drag for the symmetric Carafoli and Jukowski aerofoils as well as the general Jukowski aerofoil[7,8].

The following are among the results obtained by an analysis of the two latter cases:

(i) Whereas classical theory fails to connect C_l and C_D, the lift and drag coefficient with R, the Reynolds number of the flow, it has been possible to obtain the same by this new approach, in a neat and simple form. Hence, it has been possible to compare our theoretical results with the experimental graphs, showing almost complete agreement.

(ii) A remarkable achievement has been the discovery of a general formula for circulation which reduces to the Jukowski formula whenever the aerofoil contains a sharp point or a cusp.

(iii) Goldstein, Vol. II (1938) in Fig. 167 records an experimental graph which remained a mystery till we explained it[8].

Flows with a Vortex Wake

Flow past a circular cylinder with a symmetrical pair of vortices has been fully investigated purely by analytical means.

Studies on the vortex problem with the equation of energy and the dissipation have enabled determination of the radii of the vortex cores and the circulations about the vortices in the wake are obtained by a first order non-linear differential equation which so far has not been solved.

Our purpose behind all these efforts was to find the cause for the peculiar arrangement of the vortices known as the Karman Vortex Street.

All experimental results for the two-dimensional flows, available in the present day literature, have been fully and satisfactorily explained by Ghosh's "theory of resistance in real fluids". Altogether 35 papers were published on this subject.

(3) A New Approach to the Mechanics of a Continuous Medium

Ghosh[9] has shown that to arrive at a complete system of equations in this field, one need not turn to the physical theories like Hooke's law or to any assumptions for the determination of the stress components T_{xx}, T_{xy}, etc. The necessary and sufficient number of equations can be obtained directly by probing a little deeper into the *equation of moments*, which yields not only the symmetry of the stresses $\tau_{ij} = \tau_{ji}$ but, pushed to the fifth order, it can yield three equations for the rotation of the elements of material under consideration. This was never suspected by anybody before. And the set of these three equations with the definition of the vorticity components forms a set of nine equations for the determination of the nine unknown, u, v, w, T_{xx}, $T_{xy}(=T_{yx})$ etc., making the mathematical problem well-set.

Ghosh has also written a book[10] dealing with the flow of compressible fluids.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Gopal Prasad

My initial work was concerned with the rigidity of lattices in semi-simple Lie groups over real and non-archimedean local fields. I recall that a lattice in a locally compact group G is a discrete subgroup, such that the homogeneous space G/Γ carries a finite G-invariant Borel measure. A lattice is said to be rigid if it "determines" the ambient topological group. In my first work[1], I proved jointly with M S Raghunathan that the **R**-rank of a semi-simple Lie group can be determined from the abstract group structure of any lattice in it. Later, I proved that non-cocompact lattices in semi-simple Lie groups, with a factor of **R**-rank 1, are strongly rigid[2]. This, combined with the beautiful results of G D Mostow and G A Margulis on strong rigidity, gives the conclusion that irreducible lattices in an arbitrary real semi-simple Lie group G are strongly rigid if G is not locally isomorphic to a product of SL_2 (**R**) and a compact group. Mostow had earlier shown that to prove strong rigidity it is enough to construct equivariant pseudo-isometries between the associated symmetric spaces. The existence of such pseudo-isometries is fairly simple in case the lattice is cocompact, i.e. G/Γ is compact. However, in case G/Γ is non-compact, the existence of pseudo-isometries is not completely obvious. In case G has an **R**-rank 1 factor, using the fundamental domains constructed by Borel-Harish Chandra (for arithmetic lattices) and by Garland-Raghunathan (for arbitrary lattices), I proved that the required pseudo-isometries exist. After this work was done, I began my work on lattices in semi-simple groups over non-archimedean fields and also considered arithmetical questions on semi-simple groups over global fields. I proved that cocompact lattices in semi-simple algebraic groups over local fields are strongly rigid[3], but in case the local field is of positive characteristic, lattices are not necessarily infinitesimally rigid[4]. The proof of strong rigidity makes use of the geometry of Bruhat-Tits buildings and Mostow's ideas in his proof of strong rigidity of lattices in real semi-simple Lie groups.

In 1976, I proved strong approximation property for general semi-simple simply connected groups over global fields of arbitrary characteristics[5]. For number fields, this was proved by M Kneser and V P Platonov; however, their methods did not work if the global field is the function field of a curve over a finite field and my proof required ergodic theoretic considerations, as well as the Kneser-Tits property. The latter (i.e. the Knesar-Tits property) was proved by Platonov, and recently, we have given a very simple and conceptually a more satisfactory proof which is likely to be of interest for more general fields[6].

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A good part of my research during the last seven years has been some joint work with M S Raghunathan on the cohomological component of the congruence subgroup problem and the related problem of topological central extensions of semi-simple groups over local fields. In this work, we have determined the congruence subgroup kernel for all S-arithmetic groups in semi-simple, simply connected isotropic groups, the topological fundamental group of semi-simple algebraic group over local fields, and the "relative" fundamental groups of the S-adeles groups associated with algebraic groups over global fields. Our approach to settle these problems is different from all the earlier work in the area. It uses the structure and the geometry of the groups in a very intimate way and avoids generators and relations completely. Details of this work are given in some papers[7-9]

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

A S Gupta

Gupta has been engaged in original research on the momentum, heat and mass transfer characteristics of flows of Newtonian and non-Newtonian fluids. Boundary layer flows with heat transfer in electrically conducting fluids permeated by magnetic fields, flows of rotating fluids with or without magnetic fields, laminar and turbulent free convection problems involving plumes, infinitesimal and finite amplitude stability of various flows in hydrodynamics and hydromagnetics, with particular reference to the stability of flows of non-Newtonian fluids, are some of the areas in which Gupta has made notable contributions.

His significant contributions have been in the field of magnetohydrodynamics (MHD). His research on MHD free convection has an important bearing on alleviation of heat transfer from a surface immersed in an electrically conducting fluid permeated by a transverse magnetic field[1]. These results are also important in the problem of cooling of nuclear reactors with liquid metals (which are electrically conducting) as coolants[2]. Some of his theoretical predictions on MHD free convection heat transfer were verified experimentally by A. Emery [*J Heat Transfer, Trans ASME, Ser C* (1963) 119]. The formulae derived by him in the case of MHD channel flow heat transfer, including the effects of Hall currents and radiation, have important applications in the field of propulsion and MHD power generation.

Gupta's investigations on the capillary instability of a jet carrying an axial current with or without a longitudinal magnetic field have relevance to the problem of controlled thermonuclear reaction for generation of energy[3]. One of his results having considerable engineering interest is that transverse curvature increases the rate of heat transfer in unsteady free convection past a hot surface[4].

Gupta's work on the stability of a layer of rotating electrically conducting liquid in the presence of a uniform magnetic field parallel to the axis of rotation is important, as it takes into account finite amplitude disturbances[5]. It is shown here that in the presence of rotation, the system may exhibit subcritical instability.

His studies on magnetogasdynamic shear flow demonstrating the stabilizing influence of compressibility and magnetic field have a bearing on the problem of the earth's magnetosphere[6,7]. Another finding of some astrophysical significance is that Hall currents tend to hasten the onset of thermal instability in a layer of a conducting fluid heated from below[8].

Gupta's investigations on laminar and turbulent buoyant plumes in collaboration with Prof. C. S. Yih of Michigan

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University, Ann Arbor (USA), have applications to the problem of dispersion of fog in airfields[9]. His paper on thermal instability in a porous medium with random vibrations[10] throws light on the influence of earthquakes on the convective instabilities in the upper mantle of the earth.

Gupta's research with Prof. L. N. Howard on stability of swirling flows has applications to flows in tornadoes as well as in the problem of geomagnetic secular variation[11].

In a paper communicated by late Sir G. I. Taylor to Royal Society, London, Gupta demonstrated that homogeneous and heterogeneous chemical reactions result in the reduction of longitudinal diffusion coefficient of a solute dispersed in a solvent[12]. Dispersion of a solute in a solvent in the hydromagnetic case was also studied by him[13].

His investigations on stability of non-Newtonian and viscoelastic fluids have an important bearing on the problem of drag reduction using polymeric additives and extrusion of molten plastics[14,15].

In future, Gupta proposes to do research in the following areas: (1) Investigation of the existence of solitary waves in non-Newtonian fluids, and (2) Solution of some bifurcation problems in stability of fluid flows using catastrophe theory.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

H Gupta

Gupta has been one of the prominent mathematicians of India in recent years. The immense international influence of his research work in number theory and combinatorics, particularly in the study of partitions, is very much visible in the current research activities in these fields. He has also been instrumental in building up a strong group of active research workers and teachers in number theory and other fields in India.

He started his research activities in 1928, while working as a lecturer in Government College, Hoshiarpur. At a time when there was practically no organized research activity in mathematics in India, working on his own, he made many significant contributions to the theory of partitions. He obtained PhD in mathematics from the Punjab University then at Lahore. The examiners for his thesis were well known number theorists, Hardy and Littlewood, both of whom praised his work. The tables of partitions presented by him in his thesis had started influencing the research activities even before he submitted his thesis. Among many other things, these tables gave a proof of the falsity of a well known conjecture of Ramanujan on divisibility of $p(n)$ by powers of 7.

One of the most significant contributions of Gupta is the publication of the tables of partitions and representations of primes by quadratic forms. The tables of partitions from his thesis were published by Indian Mathematical Society in 1939.

Later, he was invited by the Royal Society to prepare more extensive tables of this type, which were published by the Royal Society in 1958 and reprinted in 1962. These tables are still among the most extensive ones available and they have proved to be very useful not only in mathematics but in many other branches of sciences, such as statistical mechanics, computer science, switching circuits, etc.

Gupta has also done extensive work on various problems on partitions and other combinatorial objects as well as in number theory. Among the 200 papers published by him so far, many are referred to in practically all standard textbooks in number theory, theory of partitions or combinatorics. His work has been mentioned in *Encyclopedia Britanica* (Vol. 16, page 604). Among many books which carry some of his work are the well known books "*Theory of numbers*" by Hardy and Wright, "*Ramanujan*" by Hardy, "*Additive Zahlen theorie*" by Ostmann, "*Topics in Analytic Number Theory*" by Rademacher, "*Combinatorial Theory*" by Riordan, "*Mehrgradige Cleichungen*" by A Golden and "*Theory of Partitions*" by G Andrews.

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He was invited by the National Bureau of Standards of USA to write a survey article on theory of partitions, for their journal. This article published in 1970 is considered to be one of the best surveys on this topic.

Among his other significant research contributions are strong generalizations of the well known Rogers Ramanujan identities, direct proofs of a conjecture of Churchhouse, remarkably simple proof of a theorem of Erdos and Lehner, which is reproduced in several books.

Many of Gupta's papers had and are continuing to have a lasting effect on the research trends, not only in number theory or combinatorics but also in other branches of mathematics. In one of his papers (published jointly with Anand and Dumir) he made a conjecture about the function giving the total number of magic squares being a polynomial of a specified degree. This conjecture was proved several years later by R Stanley, using a strong method of his own. In fact, in the same paper, Stanley used this method to prove a generalized version of the conjecture of Anand, Dumir and Gupta, for such monoids. This method was also used later for studying several other objects, in particular, partially ordered sets, magic labelling of graphs, f-sequences of some polytopes, Cohen-Macalay complexes and BIB designs.

Unlike many research workers, Gupta, while engaged in active research, did not neglect teaching, administration or devoting his time to the development of modern mathematical trends in India.

His book "*Selected Topics in Number Theory*" is considered one of the masterpieces by experts in the field. Even at the age of 83 he has not stopped working. A new book on use of Matrices in N-dimensional geometry authored by him has been published by the South Asian Publishers Pvt Ltd, New Delhi.

Gupta was appointed Professor and Head, Department of Mathematics, Punjab University, Chandigarh in 1958, which also has a centre of advanced study in mathematics. In 1966, when he retired as Director of this centre, the centre had already become one of the major internationally known centres of research in number theory and other related areas. Gupta is now an honorary Professor at the centre.

At a time when there was a craze (which unfortunately still persists in India) among research workers to publish their papers in foreign journals, Gupta notably has published most of his well known papers in Indian journals. Gupta has been member of several international mathematical societies. He was President of Indian Mathematical Society in 1963 and President of Mathematics Section of the Indian Science Congress in 1964.

Gupta devised a calendar for hundred years at the tender age of 11. This interest in calendars lasts to this day. In 1923, he devised a perpetual calendar which was exhibited at the British Empire Exhibition at Wembley and got him a medal and certificate of merit. In 1942, he devised a calendar with the help of which dates from Hijri, Vikrami and Christian eras can be interconverted. This was published in *Popular Astronomy* (USA) and has been of great use to the Panjab University office at Chandigarh when any student wants his birth certificate knowing only his date of birth as given in his horoscope.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

V S Huzurbazar

Huzurbazar was initiated into mathematical research with the publication of his first paper[1] while he was still studying for MA/MSc at Banaras Hindu University. Later, as a research scholar in the University of Cambridge in England, he worked on probability theory and mathematical statistics with Prof. Sir Harold Jeffrey, FRS, pioneer in geophysics and Bayesian inference. He also came into contact with late Sir Ronald Fisher, pioneer in modern statistical theory. Fisher had introduced his celebrated method of maximum likelihood for the estimation of parameters of a probability distribution, but several basic questions relating to this method necessitated further research. Huzurbazar[2] showed that a consistent solution of the likelihood equation is unique and that it has the property of maximum likelihood with a probability approaching 1 as the sample size approaches infinity. He showed that for the class of distributions admitting sufficient statistics, the likelihood equation has a unique solution for samples of any size, and this unique solution makes the likelihood function an absolute maximum. Huzurbazar also investigated some properties of maximum likelihood estimators in nonregular cases, where the range of a probability distribution depends on the unknown parameters to be estimated. This research work of Huzurbazar is extensively referred to in the literature in the subject, e.g. Rao C R, *Linear statistical inference and its applications* (John Wiley and Sons, New York, 1983); Lehman E L, *Theory of point estimation* (John Wiley and Sons, New York, 1983).

In his pioneering work on Bayesian inference, Jeffreys was confronted with the problem of presenting prior probabilities of unknown parameters in invariant forms to ensure consistency. He developed an interesting system of invariants of probability distributions, but unfortunately it was inadequate to represent several appropriate and satisfactory prior probability forms used by Jeffreys himself in his work. Huzurbazar[3] was the first to investigate the interesting relationship between Bayesian inference and sufficient statistics. He further developed a new system of invariants of probability distributions admitting sufficient statistics or augmented a set of sufficient statistics. In addition to interesting mathematical properties, this new system of invariants is useful to express many satisfactory prior probability forms. For his work on invariants of probability distributions, Huzurbazar was awarded the Adams Prize of Cambridge University, England, for outstanding research work in probability theory for the years 1959 and 1960. This work is extensively mentioned (Jeffreys H, *The theory of probability*, Oxford

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University Press, 1961) and was later published as a part of a book of research monographs[4].

The concept of a sufficient statistics introduced by Fisher plays an important role in statistical theory. Pitman and Koopman have obtained general forms of distributions admitting sufficient statistics in the regular case, but there was no rigorous investigation of sufficient statistics in the nonregular case. Huzurbazar[4] has done extensive research work in this field and obtained general forms. He has also obtained interesting characterizations of the normal, rectangular, extreme value distributions by the combination of properties of location—scale parameters and sufficiency. Huzurbazar's remark on marginal sufficiency is now known as "Huzurbazar's conjecture", which has created interest among statisticians in USSR.

Recently, Huzurbazar[5] proposed a rule which enables one to characterize some well-known proper conjugate prior probability distributions of Raiffa and Schlaifer and well-known improper prior probability forms of Jeffrey by the criteria of location and scale. Huzurbazar is working on the extension of this criterion.

Huzurbazar's[6] research work on orthogonal parameters broke new ground. At present, he is working on the general and basic problem of parameterization, which is important not only in statistical theory but in all sciences. He has obtained some interesting properties of the concept of "Distinctive parameterization" introduced by him.

Selected Publications

1. Huzurbazar V S, Remarks on Roll's theorem, *J Banaras Hindu Univ*, **4** (Pt 1) (1941) 33-38.
2. Huzurbazar V S, The likelihood equation, consistency and maxima of the likelihood function, *Ann Eugenics, Lond*, **14** (Pt 3) (1948) 185-200.
3. Huzurbazar V S, Inverse probability and sufficient statstics, *Proc Camb phil Soc*, **45** (Pt 2) (1949) 225-29.
4. Huzurbazar V S, *Sufficient statistics* (Marcel, Dekker, Inc, New York) 1976.
5. Huzurbazar V S, *Characterization of some well-known conjugate prior probability distributions and some improper prior distributions by the criteria of location and scale*, Paper presented at the 21st NBER-NSF Seminar on Bayesian Inference in Econometrics, Chicago University during 21 October-1 November 1980.
6. Huzurbazar V S, Probability distributions and orthogonal parameters, *Proc Camb phil Soc*, **46** (Pt 2) (1950) 281-84.

P V K Iyer

A sequence in which observations occur according to some probability law can be considered to be a random sequence. By obtain a binomial sequence of the type HHTTTHH... in which head and tail occur with probability 1/2. If, on the other hand, we take an urn containing 75 red balls and 25 white balls, we obtain a sequence of *R*'s and *W*'s by drawing a ball at random from the urn, replacing the ball drawn after each draw. The probability for *R* and *W* in this case is 3/4 and 1/4 respectively. If the urn contains *k* colours, we shall obtain a multinomial sequence involving *k* objects or *k* colours with probabilities say p_1, p_2, p_3 ... p_k such that $\sum_{r=1}^{k} p_k = 1$.

If the results of the draw are associated with a lattice of *m* rows and *n* columns, we shall have an $m \times n$ lattice arrangement of *k* characters. We can have an arrangement of these characters of an $l \times m \times n$ lattice also. For a binomial linear sequence of the kind mentioned above, it is possible to work out the probability distribution for a number of variables that can be defined for the sequence. The simplest variables that can be considered are the numbers of heads and tails or *R*'s and *W*'s in *n* trials. Many other variables can be considered for such a sequence. Feller and others have discussed the distribution of *n*, the numbers of trials to be 2, 4, 6 ... such that $s_n = e_1 + e_2 \ldots + e_n = 0$, where $e = \pm 1$ according as head or tail occurs in the various tossings. He has also considered the distribution of *n*, such that $s_1 \neq 0$, $s_2 \neq 0$, $s_3 \neq 0$, ..., $s_{n-1} \neq 0$, $s_n = 0$, i.e. the first return of s_n to the origin. Other allied distribution considered is $s_n > 0$, $s_n > s_1$, $s_n > s_2 \ldots s_n > s_{n-1}$ and calls it as ladder points in Bernoullian trials. A general method for studying the probability distribution of any variable defined for a binomial or multinomial sequence has been developed and applied for obtaining the distribution of a number of variables by the present author.

Taking a binomial sequence with probabilities *p* and *q* for the occurrence of *A* and *B*, consider the simple case for the distribution of *AB* transitions between adjacent observations. Assume $P_A(n,r)$ and $P_B(n,r)$ as the probability for the occurrence of *r* *AB* transitions in the sequence of *n*, when the first observations are *A* and *B* respectively. It can easily be seen that

$$P_A(n,r) = pP_A(n-1,r) + pP_B(n-1, r-1)$$

$$P_B(n,r) = qP_A(n-1, r) + qP_B(n-1,r)$$

Let the probability generating functions of $P_A(n,r)$ and $P_B(n,r)$ be

$$\phi_A(n) = \sum_{r=1}^{n} P_A(n,r)s^n \text{ and}$$

$$\phi_B(n) = \sum_{r=1}^{n} P_B(n,r)s^n$$

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From the equations for $P_A(n,r)$ and $P_B(n,r)$, we find

$$\phi_A(n,s) = p\phi_A(n-1,s) + ps\phi_B(n-1,s)$$

$$\phi_B(n,s) = q\phi_A(n-1,s) + q\phi_B(n-1,s).$$

The above equations lead to the determinantal equation

$$\begin{vmatrix} (E-p) & -ps \\ -q & (E-q) \end{vmatrix} \phi(n-1,s) = 0,$$

where E is the usual operator $E\phi(n-1,s) = \phi(n,s)$

It can be seen that the solution of the above difference equation is given by

$$\phi(n,s) = A\,\lambda_1^n + B\,\lambda_2^n,$$

where λ_1 and λ_2 are the roots of the quadratic

$$(\lambda - p)\,(\lambda - q) - pqs = 0$$

A and B are determined by actually writing down the generating functions $\phi(2,s)$ and $\phi(3,s)$.

If we are concerned with the distribution of AB and BA transitions, the quadratic reduces to

$$(\lambda - p)\,(\lambda - q) - pqs^2 = 0.$$

Similar equations can be obtained for any transition, say, ABA or AAB or $ABAB$ or AAA, etc. The characteristic equation will be of the fourth or higher order. The generating functions involved in these cases are $\phi_{AA}(n,s)$, $\phi_{AB}(n,s)$, $\phi_{BA}(n,s)$ and $\phi_{BB}(n,s)$.

$$\phi(n,s) = A_1\lambda_1^n + A_2\lambda_2^n + A_3\lambda_3^n + A_4\lambda_4^n,$$

where λ_1, λ_2, λ_3, and λ_4 are the roots of the characteristic equation for the generating function of the distributions. It may be noted that by putting $s = e^\theta$ in $\phi(n,s)$, we shall be getting the moment generating function of these distributions. Further, taking

$$\log \phi(n,e^\theta) = \log(A,\lambda_1^n + A_2\lambda_2^n + A_3\lambda_3^n + A_4\lambda_4^n)$$
$$= \log A_1 + n \log \lambda_1 +$$
$$\log\left\{1 + \frac{A_2}{A_1}\left(\frac{\lambda_2}{\lambda_1}\right)^n + \frac{A_3}{A_1}\left(\frac{\lambda_3}{\lambda_1}\right)^n + \frac{A_4}{A_1}\left(\frac{\lambda_4}{\lambda_1}\right)^n\right\}$$
$$= \kappa_1\theta + \frac{\kappa_2\theta^2}{2!} + \frac{\kappa_3\theta^3}{3!} + \frac{\kappa_4\theta^4}{4!} \;\ldots\ldots$$

We shall thus be getting the cumulant generating function (C.G.F.) of the distributions.

Differentiating $\log \phi(n,e^\theta)$, with respect to θ, r times and putting $\theta = 0$ in the rth differential coefficient, we get the rth cumulant of the distribution. It may be mentioned here that of the various roots of the characteristic function (i.e. determinantal equation), the maximum root, say λ_1, will reduce the unity for $\theta = 0$. All the other roots will be less than 1 for $\theta = 0$. In view of these properties.

$$\kappa_r = n\left[\left(\frac{d}{d\theta}\right)^r \log \phi\,(n,\,e^\theta)\right]_{\theta=0}$$
$$= \left[\left(\frac{d}{d\theta}\right)^r \log A + n\left(\frac{d}{d\theta}\right)^r \log \lambda_1 + \left(\frac{d}{d\theta}\right)^r \log\left\{1 + \frac{A_2}{A_1}\left(\frac{\lambda_2}{\lambda_1}\right)^n + \frac{A_3}{A_1}\left(\frac{\lambda_3}{\lambda_1}\right)^n + \ldots\right\}\right]_{\theta=0}$$

reduces to

$$\kappa_r \cong n\left[\left(\frac{d}{d\theta}\right)^r \log \lambda_1\right]_{\theta=0}.$$

Since $\lambda_1 = 1$ for $\theta = 0$, the rth differential coefficient of λ_1 is obtained by differentiating the *determinantal equation* r times and putting $\theta = 0$ after the differentiation. It should be noted that the differentiations are carried with respect to θ.

It can be seen that K_r is a linear function in n, the number of observations in the sequence. The usual conditions for normality $K_3/K_2^{3/2}$ and K_4/K_2^2 will tend to zero for fairly large values of n. Therefore, many of the distributions arising from a sequence of observations tend to the normal form.

In many cases, it may be very cumbersome to obtain the cumulants by differentiating the moment generating function. For such cases, a new procedure has been developed for calculating the factorial moments. It is known that the expected number of transitions in any sequence is equal to (the numbers of ways of obtaining the defined transitions) × (the probability for the transitions). The number of *ABA* transitions possible in any sequence of n observations is $(n-2)$ and the probability for the configuration *ABA* is p^2q. Thus, the expected number of transitions is equal to $(n-2)p^2q$. The second factorial moment is 2! (the expectation for two such transitions). In the case of a binomial sequence of *A*'s and *B*'s, the second factorial moment for the number of *A*'s is $2\binom{n}{2}p^2$. Considering transitions like *ABA*, it is possible to have two such observations (i) from five consecutive observations and (ii) from six observations divided into two groups of three as indicated below:

$\overline{AB}\underline{\overline{A}BA}$ and $ABA....ABA....$

$$\mu'_{(2)} = 2!\{(n-4)p^3q^2 + \binom{n-4}{2}p^4q^2\}.$$

Three transitions can be formed in the following ways :

$\overline{AB}\underline{\overline{A}B\overline{A}}\overline{BA}$; $\overline{AB}\underline{\overline{A}BA}$ $\overline{ABA}$; $\overline{ABA}....$ $\overline{ABA}....\overline{ABA}$

$$\frac{\mu'_{(3)}}{3!} = (n-6)\ p^4q^3 + 2\binom{n-6}{2}\ p^5q^3 + \binom{n-6}{3}p^6q^3$$

For the sake of clarification, the three factorial moments for triplets like *AAA* are given below :

$$\mu'_{(1)} = (n-2)p^3$$

$A\underline{AAA}$; $AA\underline{AAA}$; $AAA....AAA....$

$$\frac{\mu_2}{2!} = (n-3)\ p^4 + (n-4)\ p^5$$
$$\binom{n-4}{2}p^6$$

$\overline{A\underline{A}}\underline{\overline{A}\,\overline{A}}\overline{A}$; $\overline{A\underline{AA}}\,\overline{\underline{AA}A}$; $\overline{AA}\underline{A\overline{AA}}\overline{A}$;

$\overline{A\underline{AA}}\underline{A}..\overline{AAA}.;.\overline{AAA}...\overline{A\underline{AA}}\underline{A}$

$\underline{AA\overline{A}}\overline{A}\underline{\overline{A}AA}$; $\overline{AA\underline{A}}\underline{AA}..\overline{AAA}$; $\overline{A\underline{AA}}\underline{..}$

$\overline{AA\underline{A}}\underline{AA}$

$\overline{AAA}...\overline{AAA}...\overline{AAA}$

$$\frac{\mu_{(3)}}{3!} = (n-4)\ p^5 + 2(n-5)\ p^6 + 2\binom{n-5}{2}p^7 + 2\binom{n-6}{2}p^8 + (n-6)\ p^7 + \binom{n-6}{3}p^9.$$

It may be noted that the cumulants for these distributions can be obtained from the cumulants and product cumulants of the configurations involved in the distributions considered, *ignoring* the disconnected configurations.

Thus, taking for example :

$W = Z_{123} + Z_{234} + Z_{345} \ldots Z_{n-2,n-1,n}$ i.e. the sum of the variables defined between three adjacent observations.

$$\begin{aligned} K_4(W) = {} & (n-2)k_4(Z_{123}) + \frac{4!}{3!1!} \\ & \times 2\{(n-3)k_{31}\,(Z^3_{123}Z_{234}) \\ & + (n-4)k_{31}(Z^3_{123}Z_{345}\} + \frac{4!}{2!!!!!} \\ & \times 3\{(n-4)k_{211}(Z^2_{123}Z_{234}Z_{345}) \\ & + (n-5)k_{211}(Z^2_{123}Z_{234}Z_{456}) \\ & + (n-5)k_{211}(Z^2_{123}Z_{345}Z_{456}) \\ & + (n-6)k_{211}(Z^2_{123}Z_{345}Z_{567})\} \\ & + 4!\{(n-5)k_{1111}(Z_{123}Z_{234}Z_{345}Z_{456}) \\ & + (n-6)k_{1111}(Z_{123}Z_{234}Z_{345}Z_{567}) \\ & + (n-6)k_{1111}(Z_{123}Z_{234}Z_{456}Z_{567}) \\ & + (n-7)k_{1111}(Z_{123}Z_{234}Z_{456}Z_{678}) \\ & + (n-6)k_{1111}(Z_{123}Z_{345}Z_{456}Z_{567}) \\ & + (n-7)k_{1111}(Z_{123}Z_{345}Z_{456}Z_{678}) \\ & + (n-7)k_{1111}(Z_{123}Z_{345}Z_{567}Z_{678}) \\ & + (n-8)k_{1111}(Z_{123}Z_{345}Z_{567}Z_{789})\} \end{aligned}$$

It can be seen that $K_4(W)$ can be obtained by evaluating k_4, k_{31}, k_{211} and k_{1111} of the connected configurations arising in the fourth cumulant of the sum of Z's.

The discussions above are concerned with probability distributions arising from random association of points on a line with probabilities *fixed* for the occurrence of the primary events. If the probabilities are subject to the condition that the number of primary events in the sequence is n_1, n_2, n_3 . . . n_k, such that $\sum_{r=1}^{k} n_r = n$, the distribution of W is very complicated. Some of these distributions have been discussed in different publications. The moments, however, can be evaluated from the corresponding moments with fixed probabilities for the origin zero by the substitution $p_1^r p_2^s p_3^t \ldots = n_1^{(r)} n_2^{(s)} n_3^{(t)} / n^{(r+s+t)}$.

The distributions of *statistics* similar to transitions like *AB*, *ABA*, etc. have been considered for simple and double Markovian sequences, wherein the probability for the occurrence of an event depends on the previous or two previous observations preceding it. Also, the nature of the distributions like *AB*, *ABA*, $\binom{ABA}{ABA}$, etc. has been considered for the lattices of two and three dimensions. In a two-dimensional lattice, there will be $m \times n$ points (or observations) arranged in m rows and n columns. In a three-dimensional lattice, there will be $l \times m \times n$ points. The first four cumulants have been evaluated for bonds like *AB* or *AA*. In two- and three-dimensional lattices, we can consider the distribution for different types of clusters. Lieb and Bayer give the first two moments for some simple type of clusters up to $n \times 3$ lattices. The sequences and lattices considered above assume only qualitative characters. They may take quantitative values like x_1, x_2, . . ., x_k with probabilities p_1, p_2, . . ., p_k, or belong to a continuous distribution function, say $f(x)$. We may be interested in the distribution of functions like

$$\Sigma\Sigma\ (x_r - x_s)^2,\ \ \Sigma\Sigma\ |x_r - x_s|$$

The distributions of such functions have been discussed in some detail in various publications (References are given in the author's Presidential Address, Section of Statistics, Indian Science Congress, 1963). The results of investigations detailed above lead to many procedures for testing the homogeneity of two and more univariate or multivariate samples. For k univariate samples, the pooled observations are arranged on ascending or descending order, indicating the sample to which the different observations belong. We shall obtain a sequence of the type *ABABBCCABC*......, where *A*,*B*,*C*,... represent the various samples with probabilities n_1/n, n_2/n, n_3/n, etc. A test of significance, independent of the distribution of the parent population, can be made by comparing the expected and observed number of transitions like *ABA*, *AAA*, etc. or runs of varying lengths, a run being a succession of observations of the same kind, followed and preceded by an observation of a different kind.

Another way is to divide the range in which the samples lie into a convenient number of groups and compare the observed and expected number of observations in the various groups of the samples by the well-known χ^2- test on the basis $(n - 1)$ $(k - 1)$ degrees of freedom, n being the number of samples considered. If all the samples are of the same size, say m, we may arrange the samples in the form of $m \times n$ lattice and calculate the statistic

$$\Sigma\Sigma(x_{rs} - x_{r+1}\ \ x_{s+1})^2 + \Sigma\Sigma(x_{rs} - x_{r-1,s-1})^2$$

and compare it with its standard error. By identifying the k groups in which the samples lie as $A,B,C,$ ....,K, the $n \times m$ lattice if samples reduce to a lattice of points with k characters and a test for homogeneity of the samples is possible by counting the number of bonds like *AA*, *BB*, *CC*, ...*AB*, *BA*, *CA*, *AC*, etc., where the bonds are all considered along columns and diagonals. Numerous procedures are possible when the data are arranged in the form of a lattice. For bivariate samples, we may take the differences between the variates and test the samples by ordering the differences. In some cases, it may be desirable to consider the differences between the deviations of the observations from their means. This will result in the elimination for the difference between the means of the variates. The test will mainly bring out the difference between the correlations of the two samples.

Using the methods outlined above, the distributions and the factorial moments of a number of variables arising from random division of a length unity by n points distributed at random over the whole length have been considered. Some of these distributions relate to (1) the number of points lying in a given interval, (2) the distribution of the expected number of intervals between y_1 and y_2 over the whole length, and (3) expected number of intervals between y_1 and y_2 having one or two or three or more points.

Various methods have been developed to estimate the life of service stores under field conditions in collaboration with colleagues in the Defence Science Laboratory. Also, a number of papers on the analysis of field experiments in agricultural trials have been published in the *Indian Journal of Agricultural Science* during the period 1940-1944.

The Overflowing Problem of Telephone Traffic

The overflow problem in telephone traffic may be briefly described as follows : Messages arrive at the rate a per unit time and enter a set of lines, which is termed as primary route. If the primary route is full, the messages overflow to the secondary route with infinite lines and service in both the routes is at the rate unity per unit time. Kosten and Riorden have obtained the probability distribution $P(m,n)$, the probability for m and n lines to be simultaneously busy respectively in the first and secondary routes. It is believed that the solution obtained by Kosten and Riorden is exact and a number of authors have tried to confirm it. Recently, Ravi Krishna Iyer and myself have been able to establish that the solution is *not exact*. We find that the solution is satisfactory for all practical purposes, but it is not exact for a number of reasons. Some of them are outlined below. The solution is based on two sets of difference equations, viz.

$$(a + m + n)\ P(m,n)$$
$$= aP(m - 1),n) + (m + 1)\ P(m + 1,n)$$
$$+ (n + 1)\ P(m,n + 1)$$

$m = 0$ to $c - 1$ and $n = 0$ to ∞.

For $m = c$, we have

$$(a + c + n)\ P(c,n)$$
$$= aP(c - 1,n) + aP(c,n - 1)$$
$$+ (n + 1)\ P(c,n - 1)$$

$P(m,n) = 0$ for $m > c$.

The equations assume that $m\Delta t$ and $n\Delta t$ are the probabilities that a line becomes free in the two routes. While m can take values from 0 to c only, n can take values from 0 to ∞. This involves the assumption that $m\Delta t$ for $m\Delta t[0 - c]$ is the same as $n\Delta t$ for $n(0 - \infty)$. This assumption is not justifiable, though it may not affect the result seriously.

The system involves four variables: (1) m, the number of lines busy in the first route, (2) the number of lines available for service in the same route, (3) the number of lines busy in the second route, and (4) the number of lines available for service in this route. The equations above involve only two of the variables. The 2nd and 4th variables may be anything from c to ∞ and ∞ respectively. The solution obtained restricts m, the number of busy lines only and, therefore, even if the solution is exact, it does not restrict the *number of lines available for service to c. It can be anything from c to ∞.*

Kosten obtains the probability generating function (P.G.F.) for:

$$\psi(x, y) = \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} P(m, n)\ x^m y^n \text{ as}$$

$$(1 - x)\frac{\partial\psi}{\partial x} + (1 - y)\frac{\partial\psi}{\partial y}$$
$$= a(1 - x)\ \psi(x, y)$$

When $x = 1$, we have

$$\frac{\partial\psi}{\partial y} = 0 \text{ or } \psi(x, y) = \text{constant}$$

for $x = 1$.

This means that the coefficients of y are zero, i.e. no probability distribution exists for the second route for the conditions specified. Kosten's solution for the differential equation :

$$\psi(x, y) = e^{-a(1-x)} \sum_{r=0}^{\infty} c_r \left(\frac{1-y}{1-x}\right)^r$$

gives

$$\psi(1, 1) = \sum_{r=0}^{\infty} c_r = 1$$

and

$$\psi(0,0) = P(0,0) = \epsilon^{-a}.$$

But $P(m,n)$ obtained by Kosten reads as

$$P(j, k) = (-1)^k\ \phi_0(s) \cdot \sum_{k}^{\infty} (-1)^\nu$$
$$\binom{\nu}{k} \frac{a^\nu}{\nu!} \frac{\phi_\nu(j)}{\phi_{\nu+1}(s)\ \phi_\nu(s)}\ .$$

For $j = 0$ and $k = 0$, $P(0, 0)$ reduces to :

$$P(0, 0) = (-1)^0\ \phi_0(s) \sum_{\nu=0}^{\infty} \frac{a^\nu}{\nu!}$$
$$\frac{\phi_\nu(0)}{\phi_{\nu+1}(s)\ \phi_\nu(s)}(-1)^\nu$$

where

$$\phi_0(s) = \frac{a^s e^{-a}}{\nu!} \text{ and } \phi_\nu(0) = \epsilon^{-a}$$

$$\text{and } \phi_\nu(s) = e^{-a} \sum_{i=0}^{s} \binom{\nu + i - 1}{i} a^{s-i}.$$

Obviously, $P(0,0)$ is a function of s, but it should be independent of s, as seen from $P(0,0) = e^{-a}$. Besides, if we consider the system as a whole in considering $P(0,0)$, there are no busy lines in the system and the probability for this is obviously e^{-a}.

Finally, we wish to assert that infinite solutions can be produced, proceeding on the same lines as Kosten for the reason that $P(m,n) = 0$ for any value $m > c$. Many other reasons can be given for our contention that the solution of Kosten is not exact. They are being given in a separate publication.

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M K Jain

During the middle of the twentieth century, a number of nonlinear theories were proposed and applied to simple viscometric flows to explain the effects of cross-viscous forces. Jain[1,2] initiated studies on the effect of cross-viscous forces in non-Newtonian liquids to two- and three-dimensional flows. His analyses of the flow past a sphere and a circular cylinder, and the motion of an infinite cylinder in the rotating non-Newtonian liquid, have been incorporated in the books (i) *Non-Newtonian flow and heat transfer* by N. Skiand (Harper and Row, New York, 1967) and (ii) *Handbuch der Physik: Principles of Classical Mechanics and Field Theory*, III/I by C Truesdel and R A Touplin (Springer-Verlag, 1960) respectively. Jain[3] was also the first to investigate the effect of cross-viscous forces on the rotational instability (Taylor stability problem) and found that the cross-viscous forces inhibit the onset of instability. The effect of temperature on cross-viscous forces was analysed by Jain in 1962[4] and this has been described in the book *Advances in heat transfer*, Vol 12 by A B Metzner (Academic Press, New York, 1965).

Jain[5] has proposed the extremal point collocation method, which is applicable to a wide class of problems and is most convenient for a computer solution. This method has been incorporated in the books *Nonlinear Partial Differential Equations in Engineering* by W F Ames (Academic Press, New York, 1965) and *Computational Galerkin Methods* by C A J Fletcher (Springer-Verlag, 1984). This method is now taught all over the world as a viable numerical method to solve nonlinear differential equations. The use of this method as a finite element method is likely to be widespread.

In general, the recent mathematical formulation of the physical problems led to one of the following three models: (i) stiff system, (ii) highly oscillatory system, and (iii) convection-diffusion system. In high speed computation, the efficient and economical methods are high order and strongly stable methods. Jain[6] has worked out a stiffly stable method up to order eleven and has shown that no twelfth order method exists. This result led a number of research workers to attempt to obtain higher order methods than twelfth in the class of non-multistep methods. This result has been included in the text book, *Numerical Initial Value Problems in Ordinary Differential Equations* by C W Gear (Prentice-Hall, New Jersey, 1971).

Jain[7] defined the piecewise function called *Spline in Compression* which is best suited to fit a function or data which has a *convex character* and to solve the systems which are highly oscillatory. The

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convection-diffusion problems can also be solved with ease. Further, he has shown that the spline consistency relations are the fundamental equations of the discrete mechanics. He[8] has also developed a second order unconditional stable method for solving nonlinear convection-diffusion problems and no higher order method is possible. In addition, Jain[9,10] has investigated adaptive and hybrid numerical methods for solving periodic initial value problems and these are described in the book *Stiff Computation* edited by R C Aiken (Oxford Press, 1985).

Jain[11] has introduced implicit multipoint iterative methods for solving equations. A two-stage implicit fifth-order method, which is both accurate and robust, has been developed.

Jain has published a book '*Numerical Solution of Differential Equations*' [John Wiley (Halsted Press), New York, Wiley Eastern, 1979], which incorporates uptodate material on the subject[12]. This book has been recognized as a standard text in the area.

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P C Jain

In mathematical modelling of physical problems arising in science and engineering, one often gets non-linear partial differential equations. Since closed form solutions of these equations are not possible, except in a few cases, resort to numerical methods for getting the solutions is inevitable. The advent of high speed digital computers has further enhanced interest in such an endeavour. The nonlinear Navier-Stokes equations are assumed to govern the unsteady fluid flow encountered in several applications of a large number of engineering problems. Jain and his students have made systematic and basic studies for developing numerical schemes in the context of different physical situations. The proposed algorithms have been analysed for convergence, consistency and stability. For each problem, numerical examples have been solved by using the proposed algorithms on computer systems CDC 3600 and DEC 10. The superiroity and versatility of the numerical schemes so developed have been established by comparing the numerical results with the results available in the literature. The following brief account of the research work done by us for solving nonlinear problems using computers is based on the research publications in the international journals, some of which have been cited in the text.

One of the earliest methods for computations is the method of finite differences which, in most of the cases, suffer from the difficulty of instability. Several attempts have been made to overcome the occurrence of instability in the numerical schemes. We have examined it by considering the problem of fluid flow around a circular cylinder which is one of the fundamental problems because of its many applications. The transient problem is governed by nonlinear Navier-Stokes equations along with the initial/boundary conditions. The main interest is to study the existence of the limiting steady state solutions or of the well known Karman-Vortex-Street. Most of the papers on this problem discussed the steady state problem only. We have obtained a solution for the transient problem at Reynolds numbers (R) up to 50 by assuming the symmetry of the flow[1]. This is one of the basic papers and is also published in the volume, *Selected papers on numerical solutions of the equations of fluid dynamics, Applied Maths. 6 Series of Selected Papers in Physics* (Physical Society of Japan, 1973, 93-100).

It is known that the wake of the cylinder becomes unsteady at about $R = 50$. By removing the symmetry condition, we obtained the process of vortex shedding at $R = 100$ and 200; this work was presented by Jain at the first international symposium on high-speed computing in fluid dynamics, Monterey, USA, in August 1968[2].

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By further refining the mesh near the surface of the cylinder, we re-examined the problem and found the appearance of a horizontal S-shaped pattern of streamlines in the wake of the cylinder at $R = 100$ and 200. Our computed values of the Strouhal number for the shedding process are in good agreement with the empirical results.

While investigating the above fluid flows, it was surprising to find that very few efforts had been directed at the heat transfer aspects of the problem. It is known that the heat transfer phenomena in which the flow is caused by an external agency like pump or blower are termed as forced convection situations. We have made a numerical study of the unsteady laminar forced convection from a circular cylinder at $R = 100$ and 200. We have shown the superiority of our scheme by comparing the computed values of the local Nusselt number around a circular cylinder with the experimental results[3].

We have studied unsteady mixed convection heat transfer from a horizontal circular cylinder held at constant temperature with ambient fluid flowing in the upward vertical direction. The coupled momentum and energy equations are solved by ADI method for $R = 100$, $Gr = 10^4$ and $R = 200$, $Gr = 5 \times 10^4$ at Prandtl number = 0.73. An S-shaped pattern of streamlines in the wake is observed. The process of shedding of vortices is found to be faster compared to the case of forced convection. It is observed that the local drag increases due to the presence of free convection. The computed values of the mean Nusselt number are in good agreement with the correlated values given by an empirical formula[4].

In the above analysis, we found that, in general, the finite difference methods yield satisfactory results for problems in fluid dynamics and heat transfer at low and moderate Reynolds numbers. At slightly high Reynolds numbers, these methods either fail to apply or give unrealistic solutions. These conditions motivated us to develop some new numerical schemes for solving fluid dynamics problems at higher Reynolds numbers. For this purpose, we have examined the nonlinear models of elliptic, parabolic and hyperbolic types.

Quasilinearization, Invariant Imbedding and Dynamic Programming

A combined approach of quasilinearization and invariant imbedding is used for solving mildly nonlinear elliptic problems over irregular regions. The given region is imbedded in a regular region and the nonlinear problem is replaced by a sequence of linear problems using quasilinearization. This sequence is then solved by the invariant imbedding technique. The combined approach was illustrated by solving a test example. The sequence of linear problems was also solved by a dynamic programming method; this was illustrated by solving two test examples[5].

Linearization procedures (viz. outer approximation, Picard approximation and Newton approximation) and invariant imbedding technique were used to devise algorithms for the numerical solution of a second order nonlinear elliptic partial differential equation over an arbitrary simply connected bounded domain. It was illustrated by solving four test examples. Also, minimal surface equation under various boundary conditions and the subsonic fluid flow problem were solved numerically. These techniques were also used to solve coupled nonlinear parabolic equations over irregular regions. Burgers equation and two-dimensional analogues of Burgers equation and nonlinear diffusion equation were solved as test examples[6].

Quasilinearization and Galerkin Method

For solving initial boundary value problems based on partial differential equations, Galerkin method can be used; the solution yields a smooth function, which is a piecewise polynomial. We have used a combined approach of quasilinearization and Galerkin method for developing algorithms to solve Burgers equation in one space dimension up to $R = 2000$ and the coupled Burgers equations. The numerical results are in good agreement with the available results. This combined approach has been employed along with the use of the cubic B-splines as basis functions in Galerkin method to solve mildly nonlinear parabolic problems. Burgers equation has been solved as a test example. The numerical results are in good agreement with the analytical results for a wide range of Reynolds numbers up to 5000.

Splitting-up Method

A splitting-up method was investigated for the nonlinear Burgers models. By using Picard approximation for the terms involving spatial derivatives, this technique has been used for sloving nonlinear coupled Burgers equations at high Reynolds numbers. A comparison of the numerical results with those obtained by Maccormack scheme shows that the proposed method gives more accurate results. The application of the method for the solution of other nonlinear problems like the electrically conducting viscous fluid flow problem and the buoyancy driven fluid flow problem shows that the method is versatile.

Cubic Spline Function Method

For the numerical solution of heat and wave equations, the literature contains some numerical schemes known as Mitchell-Fairweather, Peaceman-Rachford, Samarskii, Gourlay-Mitchell, Lees schemes. By using the cubic spline function technique, we have developed general finite difference schemes of ADI, SOD and LOD type for solving linear partial differential equations of parabolic and hyperbolic types with constant and variable coefficients. It has been shown that particular values of the parameters of our general schemes yield most of the well known schemes available in the literature. The stability and accuracy of the general schemes are discussed. The analysis yields an 'optimal' scheme of a family which is unconditionally stable and has an accuracy $O(h^2)$. Thus, one can obtain these schemes of each family in a unified manner[7].

The application of this technique for the solution of nonlinear partial differential equations shows that it is versatile. A numerical scheme has been derived for the nonlinear Burgers equation by this technique and the numerical results have been found to be in good agreement with the exact solutions at $R = 100$ and 1000. A multistep scheme has been derived for solving nonlinear coupled Burgers equations; the stability and convergence of the scheme have been discussed. Numerical solutions have been found to tend to the steady state solutions at $R = 50$, 100, 500 and 1000.

A general finite difference scheme for solving a nonlinear hyperbolic system of equations of the first order has been derived by the cubic spline function technique. The scheme turns out to be second order accurate dissipative implicit scheme in general and third order accurate dissipative implicit scheme in particular cases. This has been illustrated by numerical examples[8].

The technique has been used to derive implicit multistep finite difference schemes for the solution of a class of nonlinear parabolic partial differential equations in which the nonlinear functions are assumed to be homogeneous. These schemes have been found to be unconditionally stable for a wide range of cubic spline parameters. They have been used for solving general nonlinear parabolic equations reducible to Burgers equations in one and two space variables and the Navier-Stokes equations[9].

A variable mesh cubic spline technique has been devised for the N-wave solution of Burgers equation. Numerical results of plane N-wave have been found to be in good agreement with the exact results[10].

Wave Motion

An approach combining the linearization method and the finite difference method has been used to devise algorithms for the numerical solution of nonlinear partial differential equations representing different types of waves. Most of these nonlinear PDEs are of the third and fourth orders. We have analysed the proposed algorithms for stability and convergence. We have studied some of the properties of the waves represented by the regularized long wave (RLW) equation and Boussinesq type equations, with particular emphasis on the interactions of the solitary waves and solitons. We have also investigated the propagation of shock waves and their interactions with the disturbance waves. The numerical results are in good agreement with the results available in the literature[11].

We have extended this technique for solving boundary control problems for nonlinear partial differential equations[12].

This technique enables one to derive finite difference schemes for nonlinear problems along with error estimates and stability criteria.

Hydromagnetic Stability

J Serrin and his coworkers at Minnesota have used the method of energy for discussing the stability problem of hydrodynamic flows. We have extended this work to hydromagnetic flows. A universal stability criterion for stability has been established without using the assumption of linearity. This work represents a basic study of the nonlinear theory of the stability of hydromagnetic flows[13].

Variational Technique

We have devised a new technique for analysing the flow of a compressible fluid past an obstacle. A method has been developed to transform a given nonlinear boundary value problem into an equivalent variational problem, which, in turn, is solved by numerical methods. We have found an estimate of the local Mach number at which a supersonic bubble appears on the surface of a circular cylinder[14].

Elliptic Operator Analogue

The numerical solution of an elliptic

problem on a closed domain was reported by Motzkin and Wasow in 1953. We have refined this result and have concluded that the ellipticity condition alone implies the existence of a nine point difference analogue of elliptic operator, which is of non-negative type. We have also obtained a sufficient condition for numerical computations in the large. Thus, we have shown that the problems related to linear elliptic operators can always be solved numerically by using an approximate difference analogue[15].

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J N Kapur

During my research work over the last 30 years, I have worked in many frontier areas of mathematical sciences. These have included frontiers with physical sciences and engineering sciences (Ballistics of guns and rockets, Non-Newtonian fluid flows, Inlet length flows, Magnetohydrodynamics, Flexible manufacturing systems), Biological and medical sciences (Population dynamics, Mathematical ecology, Mathematical physiology), Statistical sciences (Characterization of distributions, Stochastic processes), Management sciences (Mathematical programming), Information sciences (Measures of information, Directed divergence, Inaccuracy, Useful information and dependence, Coding theorems) and Social and decision sciences (Economic inequalities, Texation, Utility theory, Social structures). I have also made some contributions to core mathematics (Fibonacci numbers, K-ellipses) and mathematics education research (Mathematical modelling and applications). The contributions are spread over more than 300 research papers.

My first interest was in ballistics. During the Second World War, a large number of new guns and rockets were developed, new powders were used, new shapes of charges were employed and composite and moderated charges were tried. The theory for these new developments was, however, very weak. My first paper[1] developed methods for solving the basic equations for the general linear law of burning followed by new charges. I also developed methods for the power law of burning and got the equations solved on a computer in Germany. A high point was the development of a theory[2] which could explain the ballistics of orthodox, high-low pressure, recoil-less, high-low pressure recoil-less guns and rockets through a unified approach. I was also able to demonstrate the uniqueness of maximum pressure for composite charges. I also discussed the ballistics of multitubular charges, bore resistance and varying loading conditions and was able to achieve a good synthesis of British, French and Russian approaches to theoretical ballistics.

In fluid dynamics, I started with the study of superposable fluid flows, which enabled me to get a number of new solutions of Navier-Stokes equations. Non-Newtonian fluids had become very important in chemical industry. I studied steady and unsteady flows of power law, Bingham plastic and viscoelastic fluids in tubes and channels of various shapes. My special interest was in flows in the inlet regions of pipes and channels, in curved pipes, in heat transfer in such flows and in obtaining similar solutions My interest finally resulted in a book[3], which not only surveyed mine and my students' work, but

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also gave a survey of about 700 research papers and 50 theses produced on this subject in India.

In magnetohydrodynamics, I made contributions to superposable hydromagnetic flows, Laminar steady-state flows, stability of flows, Magnetohydrodynamic shocks, Force-free fields, Hydromagnetic turbulence, Flows of conducting immiscible fluids, and Flows of conducting non-Newtonian fluids. In compressible fluid dynamics, I studied plane and axi-symmetric jets, existence and uniqueness of flows behind curved shocks, rotational flows of ideal gases and hypersonic flows.

In all, 15 of my students got their PhD degrees in fluid dynamics and seven got their degree in mathematical programming and information theory. They made contributions to linear and non-linear fractional programming, complex, programming; coding theory and combinatorial optimization. Their work is described in my presidential address at the Indian Science Congress session in 1969[4].

My contributions to biomathematics are partially reflected in my books[5,6] and in my survey papers[7,8]. I developed a number of new population growth models and applied bifurcation and stability theories to study their behaviour. An interesting interrelationship was found between games theory, population dynamics and catastrophe theory. The stability of difference equation models and the existence of two-period fixed points in discrete-time ecological models provided specially challenging problems.

Time-delay effects are quite important in population dynamics and give rise to integro-differential and delay-differential equations. I investigated the conditions for the local stability of a number of age-structured, prey-predator and competition models. The discussion of global stability of these models raises specially difficult problems. I recently gave a list of 16 open problems and four problem areas which can be quite challenging to mathematical scientists.

Growth and stability of microbial populations is very important for the production of microorganisms for laboratory work, for pollution studies, for biogas and alcohol production, for bioconversion of solar energy and for desulphurization of coal. I studied models for competition among a number of species for a number of substrates. I also studied the effects of harvesting and diffusion in competition models.

For age-structured populations, earlier we have the classical Leslie model in terms of systems of difference equations. I developed a model[9] in terms of a system of differential equations. This gave rise to new mathematical problems which had to be solved.

Mathematical bioeconomics is a new discipline concerned with mathematical modelling for optimal exploitation of renewable biological resources like fisheries and forests. I used the techniques of calculus of variations, dynamic programming, maximum principle, linear and non-linear and fractional programming to discuss optimal management of forests, multi-species fisheries and to obtain limiting optimal and pareto-optimal solutions.

An important problem in mathematical physiology which I discussed in a series of papers was concerned with the diffusion of oxygen into living tissues from blood flowing in capillaries. I used Galerkin's method and significantly improved Blum's method to solve the resulting conjugate boundary value problem. I used similar techniques to give a new interpretation to flow of dialyzates and blood in hemodialysers.

During 1966-1969, I had developed some new measures of entropy (information). When I went to Canada in 1980, I found a large number of workers talking about Kapur's entropy of order α and type β and its applications. I also found some persons working on purely mathematical problems which this measure had given rise to. I was also impressed with the tremendous applications of the principle of maximum-entropy (PME) to thermodynamics, Statistical mechanics, Statistical inference, Economics, Geography, Search theory, Operations research, Reliability theory, Computerized tomography, Nonlinear spectral analysis, Urban and spatial structures, Pattern recognition, etc. From 1980, I have devoted most of my time and energy to this fascinating field. This has resulted in one book[10], two survey papers[11,12] and about 40 papers in this area.

I was able to characterize almost all probability distributions—univariate, multivariate, discrete, continuous, Lagrangian or sampling—as maximum entropy or minimum discrimination information distributions. I was also to derive a number of new distributions and to give a general method of deriving multivariate Lagrangian distributions from univariate distributions. I was also able to derive all the four laws of thermodynamics and the three distributions due to Maxwell-Boltzmann, Bose-Einstein and Fermi-Dirac from MEP. I was also able to derive the Gentile statistics and another class of intermediate statistics, and I applied these to many situations in economics, finance, sociology and hospital management.

I was able to show that the entropy of a maximum-entropy distribution is strictly concave and this rendered redundant a number of papers in which this concavity was proved for special cases only.

During the last 20 years, a large number of measures of entropy, directed divergence and inaccuracy have been proposed by a number of workers by a process of pseudoaxiomitization and pseudo-generalizations. I have given a comparative assessment of these measures and have proposed a number of new measures not suffering from the weaknesses of the earlier measures. The concept of useful information has been given a new meaning.

Stochastic dependence among variates is usually measured in terms of correlation coefficient ρ. This is, however, unsatisfactory, since even if $\rho = 0$, the variates may not be independent. I have given entropic measures of dependence which are invariant even for non-linear transformations and which vanish only in the case of independence. I have evaluated these measures for a number of distributions. I have also given a number of noiseless coding theorems giving lower bounds for new code word mean lengths in terms of new measures of entropy.

Statistical decomposition of Shannon's entropy and Kullback-Leibler's measure of directed divergence were well-known and have many important applications in agriculture, industry and social sciences. I have been able to give decomposition of other measures of entropy, inaccuracy divergence and useful information leading to some possible generalizations of analysis of variance.

I have also applied MEP to get solutions for problems of brand switching in marketing, of vote-switching in politics, to the estimation of missing values, to computer vision to a new interpretation of gravity models in transportation and to the derivation of the logistic and generalized logistic laws in population dynamics.

I have been able to solve a linear birth-death-emigration process in terms of the solution of a Volterra linear integral equation; the final solution has been obtained in terms of incomplete beta-functions. Non-steady state solutions for Collman's rewards and voting structure models have been obtained. Solutions of stochastic problems with multiple births and deaths have been obtained. A large scale use of confluent hypergeometric functions has been made.

I have also given new entropic measures of income inequalities and used the theory of majorization of inequalities to obtain income-tax rates for maximizing the equality of income for a given government revenue. I have also given a multivariate generalization of Arrow-Pratt measure of risk aversion.

The concepts of thermodynamics have very often been employed in economics by analogy arguments. I have been able to obtain the concepts of the economic temperature, economic entropy and economodynamics by replacing energy with cost in the derivation of laws of thermodynamics from information theory[13].

Flexible manufacturing systems represent the ultimate in technology. I discussed the problems of maximizing the expected production function (EPF) of an FMS[14]. However, we are interested not only in maximizing EPF, but also in minimizing the variance. Later, I found the expression for the variance of the production function and developed the concepts of mean-variance efficient and mean-semivariance efficient frontiers[15]. It has also been found possible to derive the product-form of probability distribution for closed queuing network models from MEP itself.

The programmes for the future include (a) finding the appropriateness of various measures of information, directed divergence, inaccuracy, dependence, etc. for various applications, (b) comparison of the results of use of different measures of information in statistics, pattern recognition, computerized tomography, etc., (c) development of efficient algorithms for entropic measures of poverty and progressivity of taxation, and (e) development of semi-open network model for FMS and algorithms for the same.

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C G Khatri

Khatri has published nearly 170 research papers in various journals of statistics and has worked in a number of areas of theoretical statistics and he has written two books[1,2]. These two books incorporate the methods and results developed by Khatri, especially in the rank of matrices, linear mixed models and growth curve model. Further, some developments in the area of monotonicity of the power of some text statistics for multivariate linear hypothesis and covariance matrices are included in one of his books[2], which also presents a new outlook in the development of distribution theory and testing of hypothesis.

A brief account of the work of Khatri in different areas of statistics is given below.

(a) *Curve fitting*: Makehm's second modification curve $y = \alpha + \rho^x + \delta x$ has been fitted by various methods and applications to decay materials have been worked out. Force of mortality curve $y = \alpha + \beta_1 \rho_1^x + \beta_2 \rho_2^x$ has been considered and internal least curve method of Hartley has been extended. Life tables for Baroda city have been developed from the 1951 census data.

(b) *Matrix algebra*: Theorems on the rank of a matrix have been developed, so that equality is attained in the case of Frobenius theorem on inequality of ranks. These results are useful in the development of results in connection with decomposition of matrices, study of idempotent matrices and Lavoie's inequality. The results of the rank of matrices are also useful in the study of new results on the g-inverses of matrices. A new commutative g-inverse has been developed. Recently, the various extensions of Kantorvich inequality have been developed[3].

(c) *Quadratic forms*: The necessary and sufficient (NS) conditions of quadratic forms in vector variables to be distributed as Wishart and/or independent have been developed in the case of (non-singular as well as singular) normal distributions of vector variables. The extension of Cochran's theorem and the NS conditions for the correlated quadratic forms to be distributed as multivariate gamma have been developed, so that they will be useful in the distribution theory. Exact distributions of the quadratic forms in normal vector variables in various forms for central and noncentral situations have been developed using results on the generalized Laguere polynomials.

(d) *Discrete distributions*: Cumulant property of power series distribution (univariate and multivariate) leads to characterization of a distribution. The classes of contagious distributions have been defined; they are capable of being

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extended to multivariate contagious distribution for the first time. The fitting methods for these distributions to live data have been investigated. The classes of multivariate Lagrangian Poisson and multinomial distributions have been studied for the first time; the study of exponential class of discrete distributions includes most of the above distributions. Rao's damaged problems have been extended to multivariate situations.

(e) *Characterization*: Characterizations are of two types: (i) of distributions, and (ii) of transformations (or statistics). In (i), some properties of distributions have been shown to be unique for certain distributions; for example, independence of some linear functions of variables, or constancy of regression of some statistics on a linear function of variables will lead to normality of the variables. Some other non-linear regressions or some other types of statistics lead to characterization of inverse Gaussian, gamma and contagious distributions. Rao's damaged problem leads to characterization of some Lagrangian discrete distributions. In (ii), normality preserving transformations have been developed; some transformations have been developed for Wishart distribution. For the Gauss Markoff model, some properties of estimates lead to characterization of the least squares estimate of the location parameters.

(f) *Design of experiments*: Variance balanced designs, orthogonality concept and connectedness in three or more factor designs were developed in collaboration with Prof. K. R. Shah. Optimality criteria in mixed model designs and efficiency criteria of designs have been investigated. Inter-intra block analyses for treatment contrasts have been developed by proposing new estimates of the common location parameters and better confidence bounds for them have been developed.

(g) *Inequalities*: Probability inequality for normal distributions and some probability inequalities for Schur functions have been developed and used in testing problems. Tchebycheff's inequality and some inequalities in matrix variables have been modified and extended. Some of these inequalities have been utilized in developing the maximum likelihood for location parameters in the growth curve model and other linear models. Cramer-Rao inequality useful for the non-regular density functions has been developed using the idea of prior distributions or reducing to the regular case.

(h) *Nonregular density function*: Inference on non-regular density requires some special technique. In this situation, maximum likelihood method and union intersection principle have been utilized for testing the parameters of *k*-rectangular distributions and their power functions have been developed. Further, a class of distributions whose range depends on the parameters have been considered for the above problems. These include location parameters of exponential distributions with two parameters.

(i) *Truncated distributions*: Problems of estimation parameters in the case of truncated normal distribution with known coefficient variation, negative binomial truncated on both sides, bivariate normal distribution (one side truncated), truncated chi-squared distributed radial error from grouped observations have been investigated in detail.

(j) *Inference on multivariate problems*: Using a new approach to the derivation of multivariate distributions—Wishart, matrix beta distributions—some results on matrix beta distribution have been investigated. The problem of derivation of the distribution of the eigen values of $S_1S_2^{-1}$ in both central and non-central situations has been investigated in detail. These results on the real variates have been extended to the complex normal variates after developing some jacobian of the transformations.

The multivariate hypotheses of testing location and scale parameters under some structures for k multivariate normal distributions having linear growth curve of the model have been investigated; the simultaneous confidence bounds were also calculated. Union intersection test procedure and maximum likelihood ratio test procedure have been developed. The exact null and nonnull distributions have been investigated and the asymptotic distributions derived using their moments. Some power properties of these tests have been investigated. The robustness of the test procedures has been shown to fall under the class of spherical distributions. Some applications to clinical trial data have been presented for developing the analysis with the help of a stochastic model.

In directional data analysis, Von Mises-Fisher distribution has been generalized to matrix variates with the help of Stiefel manifold. The estimation and the testing of the parameters of this distribution was done along with the study of asymptotic distribution[4]. Under some hypotheses, the distribution reduces to a uniform distribution on Stiefel manifold. These have led to the application of zonal polynomials in various theoretical distributions.

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1. Khatri C G, *Mathematics and matrices* (Granth Neriman Board), 1971 (in Gujarati).
2. Khatri C G & Srivastava M S, *Introduction of multivariate statistics* (North Holland Publishing Co., New York) 1979.
3. Khatri C G & Rao C R, Some generalizations of Kantorvich inequality, *Sankhya, Ser A*, **44** (1982) 91-102.
4. Khatri C G & Mardia K V, The Von Mises-Fisher matrix distribution of orientation statistics, *J R Soc Stat. Ser B*, **39** (1977) 95-106.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R S Kushwaha

In his career, Kushwaha has been associated with different subject areas at different times. He started his postgraduate work with the special functions of mathematics as a student in pure mathematics. Soon after, he shifted to applied mathematics, specially to the problems of fluid mathematics, with special reference to applications of magnetic and gravitational forces in guiding various types of motions. This marked his entry into the field of physics and he shifted from Mathematics Department of Allahabad University to Physics Department of Delhi University. There he associated himself with the study of stellar physics.

This provided him the lead to the study of plasma physics, specially as applied to stars. At Cambridge University, USA, he looked after the Section of Theoretical Plasma Physics during 1964-66. There, he obtained the certificate of performance of exceptional service. During the study of astrophysics and space physics, he acquainted himself with relativistic physics, nuclear physics and spectroscopy also.

He again shifted to mathematics, when the University of Jodhpur was established. He devoted himself to work in applied mathematics, specially fluid mechanics. His main fields of work here were statistics, operational research, functional analysis and topology. Mathematical methods became his speciality. The following were his major fields of work: (1) Special functions and their applications, specially to astrophysical and statistical distributions; (2) Stability of configurations of various stars; (3) Motions of fluid mechanics under gravitational and magnetic forces; (4) Various types of oscillations of an infinite cylinder under different conditions; (5) Energy generations in the stars; (6) Nucleogenesis under stellar conditions; (7) Mass-frequency functions in galactic clusters; (8) Motion of shock waves in stellar conditions; (9) Random fragmentation in star formation in globular clusters; (10) Neutron capturing process in stars; (11) Review of theories of figures of celestial bodies; (12) Use of modern processes of mathematics in generalizing the old results; (13) Application of operational research in developing the MBA course in the Faculty of Commerce and advising workers on queuing theory; (14) Application of computer programme in defence research; (15) Statistical analysis of utilization of rainfall water by surrounding vegetation in the arid zone; and (16) Comparison of Gumbel's and Jenkinson's method of estimating probable maximum rainfall intensities over India for different return periods.

To sum up, Kushwaha has been associated with different fields of research at different times, but all the time emphasis

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has been on the application of mathematics to the physical problems and development of methods for the improvement of the situation under particular physical conditions.

Kushwaha has been associated with a number of national and international scientific bodies in different capacities.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R S Mishra

Mishra started research work in differential geometry in 1944 at the University of Delhi under the guidance of late Prof Ram Behari. He was enrolled in St. Stephens College and worked on the topic of rectilinear congruences. Before him rectilinear congruences were studied by ordinary methods or at the most with the help of vectors. He was the first to deal with rectilinear congruences with the help of tensor algebra and tensor calculus and this had a wide impact. He obtained PhD on the above topic in January 1947 and was the first PhD of Delhi University in all the faculties. After obtaining PhD, he worked on rectilinear congruences and extended them to curvilinear congruences with the help of tensors. He guided a number of students on the above topics. On the basis of his published works he obtained DSc degree from Lucknow University in 1952. In 1954, he was awarded Banerjee Research Prize for the best work of the year in the Faculties of Arts, Science, Law and Commerce.

The two greatest achievements of the present century are theory of relativity and quantum mechanics. Albert Einstein was of the firm view that there could not be two different theories—one for macroscopic distances (theory of relativity) and the other for microscopic distances (quantum mechanics). He toiled hard for 35 years to get a unified field theory and ultimately gave it in the form of four sets of equations without giving their solutions. The first set of these field equations which consisted of 64 equations in 64 unknowns presented the greatest difficulty. In order that it might have physical applications, a tensorial solution was absolutely necessary. Though mathematicians and physicists in various countries started working on the problem, it baffled the scientists throughout the world. Even physicists like Schrodinger who wrote three papers on the subject concluded the last paper with the remarks,'It is next to impossible to give a tensorial solution to these equations. This is hard to believe unless one has tried'. When these remarks came from Prof Schrödinger, scientists throughout the world gave up their attempts to obtain tensorial solutions to these equations, thinking that Einstein was wrong. But there were two brave scientists, Mime Tonnelat of Paris and Prof Vaclav Hlavatý of Indiana University, Bloomington, USA, who gave solutions to these equations. Though their solutions were only partial, they proved that Einstein was not wrong and it was his genius that he could give these four sets of equations. Mishra happened to visit Bloomington, Indiana, USA, in 1957-58 and working with Prof. V Hlavatý devised his own method known as the method of 'repeated substitution' and gave complete solutions to these equations. His solutions are the best

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solutions obtained so far. These solutions were published in the form of three long and condensed papers in *Tensor* (Japan), *Journal of Mathematics and Mechanics* (USA) and *Nuovo Cimento* (Italy) under the title 'Einstein's connections'. The problem was tackled in index notation. Later, the same problem was tackled by Mishra in index-free notation and was published in *Tensor*.

Mishra again visited Indiana University in 1961-62 and published several papers in Einstein-Maxwell fields. In these papers, some of the open problems have been solved and the results had great impact.

In collaboration with Prof Hlavatý, Mishra worked after coming back to India in 1962 on another important problem, 'Classification of Riemann-Christoffel Curvature Tensor in Space-Time V'. They jointly published four papers which have had wide applications.

Prof Hlavatý died in 1969. At the time of his death, he was working on a problem concerning field equations, but he could not complete it. He left a note on his death bed, 'In case of my death or incapacitation, Prof R S Mishra would be willing to complete it'. Mishra completed the work and sent it to Indiana University where Prof Hlavatý had been working as Distinguished Service Professor. It runs into more than 100 pages.

Mishra was the first in India to work on shock waves in fluid mechanics. He wrote a few papers on the subject and created large schools at Gorakhpur University, Allahabad University and Banaras Hindu University. In all these three places he was Professor and Head of the Department of Mathematics.

Mishra has worked extensively and intensively on differential geometric structures on manifolds. He has developed his own notation in the theory of manifolds. This notation is modern, important and useful and simplifies calculations to a great extent. He has published a large number of papers on manifolds. These papers are in index-free notation. He is one of very few geometers in the world to write such a large number of papers in index-free notation. In 1984, he brought out a book '*Structures on a Differentiable Manifold and Their Applications*' (Chandrama Prakashan, Allahabad). The whole book is in index-free notation. The last chapter (thirteenth) of the book is on 'Applications of differential geometric structures to the theory of relativity', which sums up Mishra's contribution in the field.

Mishra has published over 250 research papers in differential geometry, relativity, fluid mechanics and numerical analysis. His work has been extensively quoted in research papers, Russian books and standard works like Schouten's 'Ricci Calculus' and Hlavaty's 'Einstein's Unified Field Theory'.

More than fifty research scholars working under his guidance have obtained their PhD and DSc degrees from the Universities of Delhi, Lucknow, Agra, Gorakhpur, Allahabad, Banaras Hindu University and Kumaon. He is still very active and even as Vice-Chancellor, first at the University of Kanpur and later of Lucknow, he has been publishing papers in international journals.

S K Mitra

Estimation Theory

Uniformly minimum variance unbiased (UMVU) estimators for the parameter θ were obtained for a fairly wide class of discrete distributions introduced by Noak, which includes the binomial, Poisson, negative binomial, etc. and their truncated forms. For a sample of size n drawn from a Poisson distribution truncated below at the origin, the UMVU estimator was tabulated[1] for sample sizes $n = 1(1)\ 10$.

Statistical Analysis of Categorical Data

In various applications, data arise in the form of frequencies in several classes or categories. Analysis of categorical data is an area of vigorous contemporary research work. Mitra was one of the first to study this area assuming multinomial sampling. He showed how several techniques of analysis of variance or multivariate analysis for continuous data have their natural analogues in the analysis of categorical data[2]. The Pitman limiting power of the goodness of fit chisquare test was computed when the parameters appearing in the expectations of the multinomial frequencies are estimated by the method of maximum likelihood or other equivalent procedures[3]. Mitra later obtained corrections to the expressions for the goodness of fit chisquare statistic that are necessary when the frequencies arise from a compound multinomial distribution.

Distribution Theory

In his book *Linear Statistical Inference and Its Applications*, Rao introduced the Wishart distribution in a density free way which allows for a unified treatment of the singular and non-singular Wishart distributions. Mitra similarly studied the matrix variate beta distribution (introduced by Kshirsagar and others) which led to several results that were hitherto unknown. Rao had conjectured that if s, a real symmetric random matrix of order $p \times p$ and Σ, a real symmetric positive definite matrix also of the same order, be such that the ratio of quadratic forms $a'S\,a/a'\Sigma\,a$ is always distributed as a chisquare with a common degree of freedom, then S would follow a Wishart distribution. A counter example constructed by Mitra[4] showed the conjecture to be untrue. He proposed additional conditions which were shown to ensure a Wishart distribution for the random S matrix. For statistics T with an asymptotically normal distribution, the Cornish-Fisher approximation provides formulae for approximate calculation of critical values of T in terms of the corresponding critical values of the standard normal distribution, valid for moderate sample sizes. For the variance

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ratio distribution where one of the degrees of freedom is small, the normal approximation is hardly exact enough and one prefers to work with the gamma approximation. Formulae similar to the Cornish-Fisher expansions were computed for the gammaization of the variance ratio.

Linear Models

In a joint work, C R Rao and Mitra introduced the unified least squares theory valid for linear models where the dispersion matrix is proportional to a known matrix (possibly singular). For such singular models, the best linear unbiased estimator (BLUE) of an estimable parametric function (EPF) may have distinct linear representations. Mitra later answered in the affirmative a query raised by Albert whether the class of estimators derived through the unified least squares method include certain expressions for the BLUE that Albert had later derived through another argument. Kruskal, Rao, Watson and Zyskind have studied conditions on the dispersion matrix that ensure that the simple least squares estimators (SLSE) remain best linear unbiased. In another paper with C R Rao, Mitra studied the extent to which specification errors could arise both in the expectations and the dispersion matrix of random variables, with the SLSE still retaining its optimality. The study for the first time covered other aspects of the Gauss-Markov theory, including sampling distributions and test of linear hypothesis[5]. Mitra later studied the completely general linear model with an arbitrary parameter space for the structural parameters and also the unknown disperson matrix. He indicated a method for obtaining an admissible linear unbiased estimator for an EPF which coincides with BLUE if the BLUE exists. General linear models were characterized which share with the standard Gauss-Markov model the properties that every EPF has BLUE and the variance of the BLUE admits an unbiased quadratic estimator. In fractional replications used in designed factorial experiments and elsewhere, statisticians have assigned to themselves the task of estimating non-estimable parametric functions without explaining the context where such a step would be meaningful. Mitra has shown that one such context could be to assume a bounded parametric space for the structural parameters. Assuming an ellipsoidal parametric space, Mitra has done a numerical comparison of several alternative methods for estimation. Inference with such models appears to be a fertile area for future work.

Sampling Theory

In one paper[6], Mitra and Pathak proposed an algorithm for optimal integration of two or three probability proportional to size surveys covering the same population units. The algorithm ensures that the expected number of distinct units is the least for a sample size 1 for each survey. A counter example by Chandrasekaran shows that the algorithm cannot be extended in the obvious way to four or more such surveys. The integrated survey brings in interesting compound estimation problems which await solution and the algorithm itself may require modification to cover simple random sampling with replacement. In another paper, Mitra and Pathak studied the asymptotic normality of the estimator of the population mean in fixed cost simple random sampling which has relevance when the cost of the survey depends on the sampled units as well[7].

Generalized Inverse of Matrices

This is an area in which interestingly, statisticians have made valuable contributions mainly because they were among the first to realize the usefulness of this concept in various statistical applications. A little later came the applications in electrical network theory.

Mitra's book on this subject with C R Rao was like a crusade against the Moore-Penrose inverse. The Moore-Penrose inverse is certainly useful, but until recently its role was somewhat overemphasized mainly because of one's obsession with uniqueness. There are problems where other inverses that are computationally much simpler could serve the purpose just as well and some others where the Moore-Penrose inverse should definitely not be used. Nonuniqueness of a generalized inverse in the sense of Rao leads to interesting invariance and characterization problems some of which were solved by Mitra. Part of his work appeared in joint publications with C R Rao and P Bhimasankaram. For example, a matrix is uniquely determined by its class of generalized inverses[8], if A and B are complex matrices of the same order and the Moore-Penrose inverse of A is a generalized inverse of B and vice versa when A and B are equal[9]; if G is a generalized inverse of A and A of G and further for some positive integer $\nu \geqslant 2$ $(GG\#)^{\nu}$ is a generalized inverse of $(A\#A)^{\nu}$, then G is the Moore Penrose inverse of A, where # indicates the adjoint of the matrix.

In an n-port electrical network involving only resistors, the impedance matrix which connects the current vector with voltage vector is symmetric non-negative definite. When two such networks with impedance matrices A and B are connected in parallel, the impedance matrix of the parallel connection is given by $A(A + B)^{+}B$, the parallel sum of A and B (Anderson and Duffin). This operation is commutative and the parallel sum is symmetric non-negative definite with its range as the intersection of the ranges of A and B, and has several other interesting properties. The commutativity of the parallel sum was used by Mitra[10] for solving a pair of consistent matrix equations $A_1XB_1 = C_1$ and $A_2XB_2 = C_2$. In extending this concept to pairs of matrices not necessarily symmetric n.n.d., it was tempting for Mitra to replace the Moore-Penrose inverse by an arbitrary generalized inverse. A pair of matrices A and B were said to be parallel summable if $A(A + B)^{-}B$ is unique in spite of non-uniqueness of the generalized inverse $(A + B)^{-}$. Mitra showed that the parallel sum here has properties that are strikingly similar to those of the parallel sum of a pair of n.n.d. matrices, as shown by Anderson and Duffin. The class of symmetric non-negative definite matrices of the same order is not a saturated (maximal) class of pair-wise parallel summable matrices. A larger class are the quasi-positive definite matrices of Mitra and Puri[11] and even larger are the almost definite matrices of Duffin and Marley if one restricts oneself to any one of the two types. This classification of the a.p.d. matrices is due to Mitra and Odell. The search for a maximal class has still not ended. The class of generalized inverses of the parallel sum of A and B coincides with that of $A^{-} + B^{-}$ of arbitrary generalized inverses of A and B. Mitra showed that for a pair of matrices A and B if there exists a matric C such that the class of generalized inverse of C coincides with that of A^{-}

$+ B^-$, then A and B are parallel summable and C is the parallel sum of A and B.

Mitra[12] showed how the shorted finite dimensional positive operators of Krein-Anderson-Trapp are connected with two subclasses of generalized inverses considered by Rao and Mitra[8]. When some of the ports of an *n* port electrical network (involving only resistors) are connected to earth, the impedance matrix of the resulting network is given by an appropriate shorted version of the original impedance matrix. Mitra[13] was recently able to provide a meaningful extension of this concept to matrices not necessarily symmetric n.n.d., bringing in suitable shortability restrictions and show that his definition parallels the definition of Krein-Anderson-Trapp if only the Lowner ordering used here is replaced by the minus partial order of Hartwig, which could be defined even on rectangular matrices. The whole theory of matrix inequalities awaits rewriting in terms of the recent partial orders of Drazin and Hartwig. As an interesting byproduct, using the symmetry of the shorted positive operator, Mitra was able to provide solutions of linear matrix equations with prescribed feasible ranks for EXF (E, F are given matrices). This is of interest to electrical engineers and was posed to Mitra by a member of this profession.

An optimal inverse introduced by Mitra strikes a balance between the semi-least squares and minimum seminorm functions of the generalized Moore-Penrose inverse also studied earlier by C R Rao and Mitra. It has properties quite similar to those of the generalized Moore-Penrose inverse. The generalized Moore-Penrose inverse was shown to be the limit of a properly chosen sequence of optimal inverses. Mitra also used the generalized inverse to solve nonlinear matrix equations $AXAXA = AXA$ and $XAXAX = XAX$, which occur in the distribution theory of quadratic forms in multivariate normal variables and in another paper with C G Khatri to find hermitian and sign definite solutions of linear matrix equations[14].

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N Mukunda

It is a characteristic feature of quantum mechanics, as compared to its classical counterpart, that it has given a greatly increased role to symmetry and group structure of physical systems at a very fundamental level. It has led to a deep fusion of the ideas of dynamics and symmetry, which has increased with the advent of relativistic quantum mechanics, field theory and elementary particle physics. In turn, these points of view have prompted a re-examination of the basic formalism of classical dynamics itself. To a considerable extent, the work to be described below has been inspired by these general trends.

A good part of my early work deals with the representation theory of certain compact and non-compact Lie groups relevant to particle physics. The groups considered were SU(3), G_2, the Lorentz groups SO(2,1) and SO(3,1), the Poincaré group, and the group SL(3,C). In this area, the noteworthy results are: (i) reduction of the unitary irreducible representations (UIR's) of the Lorentz groups with respect to suitable non-compact subgroups; (ii) a similar analysis for the UIR's of the Poincaré group, especially the space-like representations; (iii) study of the unfamiliar continuous spin representations of the Poincaré group; (iv) a new approach to the Clebsch-Gordan problem of SO(2,1); and (v) a resolution of the multiplicity problem for the UIR'S of SL(3,C) with respect to its maximal compact subgroup SU(3).

An interesting application of these studies on group representation theory has been in the context of the Majorana wave equation. In contrast to the familiar finite-dimensional wave equations, these are infinite-component equations based on two very special UIR's of SL(2,C). Among their solutions one finds time-like, light-like and space-like UIR's of the Poincaré group, the latter two being of the continuous spin-type. The problem of proving the completeness of the solutions of these equations is a non-trivial one, and involves group representation theory, properties of special functions as well as analytic function theory. By judicious use of all these, the completeness property has been established.

A somewhat earlier use of non-compact groups and their unitary representations concerns the concept of the non-invariance group in classical and in quantum mechanics. An attempt was made here to describe not only the symmetries but the entire spectrum of states of a dynamical system by a single UIR of a (necessarily non-compact) Lie group.

One of the important recent advances in the formalism of classical dynamics has been the development by Dirac of a

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generalized Hamiltonian dynamics to handle the so-called singular Lagrangian systems. In this theory, Dirac has set up new mathematical methods and concepts of great power and elegance. I have long been interested in this area, and a good part of my work concerns the role and treatment of symmetries within Dirac's framework. This has led to new insights, achieving for symmetry what Dirac had done for dynamics. A comprehensive differential-geometric study has also been attempted by me in collaboration with others. In the same vein I have studied Hamilton-Jacobi theory, as well as the similarities in the transformation theories of classical and quantum mechanics, always laying stress on the role of symmetry in dynamics.

The general methods of constrained dynamics are finding applications in many problems in current research and I have been able to contribute to some of them. A well-known and long-standing result of classical relativistic Hamiltonian dynamics due to Currie, Jordan and Sudarshan is the 'No Interaction Theorem': under reasonable physical conditions, and in the framework of Dirac's instant form of relativistic dynamics, a system of point particles cannot include interactions if the particle world lines are objectively real. A way to circumvent this result was suggested by several authors some time ago, using constrained Hamiltonian methods; however, these attempts remained incomplete in essential respects. In collaboration with others, I have re-examined this problem and shown that the essential new point allowing an evasion of the theorem is the use of a dynamical rather than kinematical evolution parameter. This calls for an extension of Dirac's formalism, requiring 11 generators to describe relativistic dynamics instead of just 10. As part of this study, a new way of formulating the dynamics of such systems, laying particular stress on the SO(3,1) subgroup of the Poincaré group, has been developed.

Another technically related development has been a theory of relativistic systems with internal structure. This is intended to be a classical starting point for the concept of a Regge trajectory, and so stands halfway between the picture of a simple particle with definite mass and spin, and the relativistic string. A particularly interesting model based on spinorial internal variables has been developed. A more comprehensive and thorough study of all such systems has been started and is close to completion.

Differential geometric and topological methods are finding increasing use in physical problems today. Apart from the work already cited regarding constrained systems, I have in collaboration examined aspects of nonabelian monopole solutions of gauge theories with spontaneous symmetry breakdown. This is a recent development of great importance and we have shown that due to the non-trivial topology of the monopole, the process of symmetry breakdown gets affected in an unexpected way. In particular, the unbroken or residual symmetry in such situations is strongly influenced by the monopole structure.

Another general area of work worthy of mention is that of quantum optics. I have long had an interest in this field, and have tried to understand the special role of coherent states, and more recently the group theoretical structure of paraxial optics. Related to the former is the discovery of discrete diagonal coherent state approximations to density matrices in quantum optics. This exposes some very subtle properties of coherent states which at the same time provides an illuminating and direct proof of the diagonal coherent state representation of Sudarshan. Turning to paraxial optics, it appears somewhat surprising that a compact and consistent formalism to handle polarization properties of light beams apparently did not exist till recently, and the subject of Fourier optics was essentially restricted to the scalar theory. We have made a significant contribution to this area, using the idea of Dirac's front form of relativistic dynamics, and have set up the basic formalism of Fourier optics for the Maxwell field.

For the near future, I expect to devote attention to the following areas: (1) Extended systems in classical and quantum theory, (2) Canonical and other aspects of nonlocal field theories, (3) Topological and asymptotic behaviour of field theories, (4) Systematics of Fourier optics beyond first order systems, and (5) Differential geometric methods in dynamics.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

K R Nair

Experimental Designs

In the early twenties, while statistically analysing and interpreting the data of field trials on different varieties, levels of manuring, etc., of agricultural crops, at the Rothamsted Experimental Station, England, R A Fisher developed a new branch of statistical methods known as 'Design and Analysis of Experiments'. It was based on three principles which he called: Replication, Randomization and Local Control. Another powerful technique Fisher developed was 'Factorial Experimentation'.

With the establishment of the Indian (then called Imperial) Council of Agricultural Research (ICAR) around 1931, Fisher's techniques were introduced in Indian agronomy. To provide training in them to agricultural research workers, ICAR gave financial support to the Indian Statistical Institute (ISI) which, by a fortuitous coincidence, was founded by the late Prof P C Mahalanobis at Calcutta in 1931, almost at the same time as ICAR.

Since then, Indian statisticians got interested in this new methodology of design and analysis of experiments. The earliest research paper by an Indian statistician on this subject was the one published by Nair[1].

Fisher's visit to India in 1938 at the invitation of the Indian Statistical Institute gave additional impetus to Indian statisticians to do research on experimental designs. During 1936-37, F Yates, who had succeeded Fisher at Rothamsted, invented balanced incomplete block (BIB) designs and lattice designs for single factor experiments involving large numbers of treatments. As an interaction of the close personal contact with Fisher, who expounded the virtues of Yates' designs to the statisticians at ISI, R C Bose and Nair jointly formulated the partially balanced incomplete block (PBIB) designs in 1939, the definition of which was slightly amended by Nair and Rao in 1942. As Fisher later remarked, the PBIB designs provided the 'missing link' between the BIB designs and lattices.

Starting from these basic papers of Bose, Nair and Rao, extensive combinatorial work has been done and a plethora of designs unearthed by statisticians the world over.

In recognition of the research work done in the field of experimental designs, Nair was elected a Fellow of the American Statistical Association in 1951 with the citation: "One of the world's leaders in the construction and properties of incomplete block designs".

Order Statistics

Let $X_1, X_2, \ldots, X_n$ be a sample of size n

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from a specified or unspecified population, arranged in non-decreasing order, so that $X_1 \leqslant X_2 \leqslant \ldots \leqslant X_n$. Then, $X_1, X_2, \ldots X_n$ are collectively called the order statistics (plural) of the sample, and X_i ($i = 1, 2, \ldots n$) is called the ith order statistic of the sample.

Nair had made special studies of the properties of well-known linear functions of order statistics like the median; mean deviation from the median; range; extreme deviate from the sample mean; and Gini's mean difference. Some of his results, pulbished in 1948, on bounds of the extreme deviate from the sample mean were rediscovered in 1968 by Prof Paul A Samuelson, in a paper entitled "How Deviant Can You Be?" [*J Am Stat Ass*, **63** (1968) 1522-25] in which he gave some interesting applications and potential uses of these inequalities.

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V V Narlikar

My research career began in 1930 and ended in 1973. The ocean of science about me was visited by numerous storms during this period and it was not easy to keep one's head above water all along.

I passed the Mathematics Tripos II in 1930 winning the highest distinction of the time, 'B Star' along with several others: besides I was awarded the Tyson Medal and Prize for Astronomy. I began work under Prof H F Baker who had lectured to us on "Brown's Lunar Theory". In July 1930, I began work on Liapounov's famous paper on rotating fluid bodies. In September 1930, I gave a written review of Liapounov's method, work and achievements. Prof H F Baker was too busy with other work and he sent my review to Prof Sir Joseph Larmor under whose guidance I was to work further. As a result of the work I was awarded an Isaac Newton Studentship of £250 a year for one year only in the first instance, in October 1930. A year afterwards the award was made for three more years. I had already begun work under Prof Sir Arthur Eddington on Relativity and Eddington's Fundamental Theory. At Cambridge I was awarded a Rayleigh Prize in April 1932 for distinguished research work.

In May 1932, I returned to India with the intention of resuming my work at Cambridge for two more years from October 1932. However, the Banaras Hindu University offered me excellent opportunities of teaching and research in August 1932. I accepted the offer and continued there till 1960.

It was at Banaras that I had opportunities to learn and teach many topics in mathematics, such as (1) Modern algebra, (2) Groups, characters and applications, (3) Wave mechanics, (4) Spinors and their applications, (5) Hilbert's space and quantum mechanics, (6) Stellar structure as it developed after 1940, etc. methods of mathematical physics, statistics, higher dynamics and the potential theory were parts of compulsory courses for M.A.-M.Sc. students of mathematics. Teaching helped me to understand the subject better and it stimulated research.

In 1947, K R Karmarkar had produced a number of interesting papers on the problem of equivalence of metrics, but the two papers which received considerable attention later, in the research investigations in general relativity, were the joint paper of Narlikar and Karmarkar on the curious solution of Einstein's field equations (*vide "Binstein Spaces"* by A Z Petrov, 1969, 197) and the joint paper on the fourteen scalar invariants of a general gravitational metric [*Proc Indian Acad Sci*, **29** (1949) 91-97].

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About this time, Einstein's new version of a generalized theory of gravitation was out. Ramji Tiwari examined the nature of interaction between the electromagnetic field and the gravitational field. Very lengthy calculations were carried out independently by him and by Narlikar and two papers explaining the character of the interaction came out in 1948 and 1949. This and the later work done at Banaras on allied topics has been referred to in V Hlavaty's 'Geometry of Einstein's Unified Field Theory' (1958). Tiwari's Ph.D. thesis later published (1969) by the Banaras Hindu University reports most of the work done later on the same topic.

P C Vaidya had obtained while at Banaras the relativistic solution for a non-static mass [*Curr Sci*, **12** (1943) 183]. A few years later, he and Narlikar published some papers jointly on the electromagnetic effects of such fields. Vaidya's solution (1943) has now become famous in general relativity and much of the later work by Vaidya and his pupils has attracted wide attention.

After 1950, K P Singh commenced a series of joint investigations on the physical significance of several metric invariants. Among the several publications of this period may be mentioned the one on the role of the three-index symbols in general relativity, where an analysis is made of the indeterminateness implicit in the co-ordinates of general relativity and a new derivation of the inverse-square law of gravitation is given.

While at Banaras B R Rao's work for the Ph.D. was on the derivation of the equations of motion from the field equations themselves. C Infeld, who was associated with A Einstein and B Hoffmann in the classic work on the topic was an examiner of Rao's Ph.D. thesis. He was impressed by the corrections and improvements made by Rao in the method of approximations. In a couple of joint papers published in the *Proceedings of the National Institute of Sciences of India* in 1955 followed by several other papers, including the one on the calculations of the motion of the perihelion of Mercury in 1959, in the same journal, his important results have been reported. The work is referred to in *'Motion and Relativity'* (1960) by L Infeld and J Plebanski.

At the University of Poona, Narlikar and colleagues have been interested in problems arising out of the Petrov classification, the equations of motion in general relativity, generalized field equations, spherically symmetric metrics and their curvatures, etc. Special mention deserves to be made of M M Kumar, who has obtained, in a number of papers, interesting properties of conformal metrics and conformally related space-times.

Our recent research activity has been concerned mainly with (1) the exact solution of Einstein's equations of General Relativity, (2) the solutions of unified equations of Einstein and Schrödinger, separately and in different forms, (3) the equations of motion as derived from the field equations, (4) the fourteen scalar differential invariants of the Riemannian metric and their physical significance, and (5) the geometrical and physical properties of metrics satisfying Einstein's field equations.

When I retired from the University of Poona in 1973, many new problems had arisen. It is interesting to see how new techniques have arisen giving us a deeper insight into problems which were unknown in the days of Pauli, Einstein and

Heisenberg and leading to a new vision of interconnectedness in cosmology and particle physics. It is with deep interest that I watch this interconnectedness, attracting even problems of biology and a mathematician's vision of the fundamental questions of man's role in the universe.

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K R Parthasarathy

My work during the last five years, done in collaboration with and on suggestions from several friends, has been on the interplay between the theory of stochastic processes and quantum theory. There are two important classical stochastic processes, namely, Brownian motion and Poisson process, the former possessing continuous sample paths, which are differentiable nowhere and have infinite length in every finite interval and the latter having just unit jumps after independent and identically distributed exponential waiting times. Practically all interesting models of stochastic processes are constructed from these two fundamental processes by the powerful tools of stochastic calculus which received a tremendous flowering during the last 60 years at the hands of P Lévy, N Wiener, J L Doob, K Ito, P A Meyer, S R S Varadhan and many others. The induction of ideas from quantum theory, such as Fock space, the operators of annihilation, creation and number and other related notions into the theory of stochastic processes broadens the perspective considerably and enabled us to develop a new quantum stochastic calculus leading to some surprising results, a few glimpses of which are given here.

To any complex separable Hilbert space **h** we associate its *boson Fock space*

$$\Gamma(\mathbf{h}) = \mathbb{C} \oplus \mathbf{h} \oplus \mathbf{h} \textcircled{s} \mathbf{h} \oplus \ldots \oplus \mathbf{h}^{\textcircled{s}^{n}} \oplus \ldots$$

where $\textcircled{s}$ denotes symmetric tensor product. For any $f \in \mathbf{h}$ let $\psi(f) = 1 \oplus f \oplus (2!)^{-1/2} f^{\otimes^2} \oplus \ldots \oplus (n!)^{-1/2} f^{\otimes^n} \oplus \ldots$ denote the associated coherent vector and let $a(f)$ and $a^{\dagger}(f)$ be respectively the *annihilation* and *creation* operators satisfying the relations

$$a(f)\,\psi(g) = \langle f, g \rangle\, \psi(g),$$

$$a^{\dagger}(f)\,\psi(g) = \frac{\mathrm{d}}{\mathrm{d}x}\,\psi(g + xf)\Big|_{x=0}.$$

For any operator T on **h** let $\lambda(T)$ be the operator on $\Gamma(\mathbf{h})$ defined by

$$\lambda(T)\psi(f) = \frac{\mathrm{d}}{\mathrm{d}x}\,\psi(e^{xT} f)\Big|_{x=0}$$

We call $\lambda(T)$ the *conservation* operator corresponding to T. Whereas $a(f)$ and $a^{\dagger}(f)$ map the n-particle subspace $\mathbf{h}^{\textcircled{s}^{n}}$ into the $n-1$ and $n+1$ particle subspaces $\mathbf{h}^{\textcircled{s}^{n-1}}$ and $\mathbf{h}^{\textcircled{s}^{n+1}}$ respectively, $\lambda(T)$ leaves the n-particle subspace invariant, thereby justifying the names annihilation, creation and conservation.

When $\mathbf{h} = L_2[0, \infty)$, we write for any $t > 0$

$$A(t) = a(\chi_{[0,\,t]}),\ A^{\dagger}(t) = a^{\dagger}(\chi_{[0,\,t]}),$$
$$\mathbf{\Lambda}(t) = \lambda(\chi_{[0,\,t]})$$

where $\chi_{[0,t]}$ denotes the indicator function of the interval $[0, t]$ in the first two equations and the projection operator of multiplication by $\chi_{[0,t]}$ in the last equa-

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tion. The boson Fock space $\Gamma(L_2[0, \infty))$ admits the decomposition $\Gamma(L_2[0, \infty)) = \Gamma(L_2[0, t]) \otimes \Gamma(L_2[t, \infty))$ for every $t > 0$. If $t \rightarrow X(t)$ is an operator valued map such that $X(t) = X_0(t) \otimes I^t$, where $X_0(t)$ is an operator in $\Gamma(L_2[0, t])$ and I^t is the identity operator in $\Gamma(L_2(t, \infty))$, then $X = \{X(t)\}$ is called an *adapted process*. If, in addition, for every $f, g \in L_2[0, \infty)$ with support in $[0, s]$ and $s < t$, the identity $<\psi(f), X(t)\psi(g)> = <\psi(f), X(s)\psi(g)>$ holds, then X is called a *martingale*. In this sense, the three processes A, $A^\dagger$, Λ are martingales. If $X = \{X(t)\}$ is an adapted process such that each $X(t)$ is self-adjoint and the different $X(t)$'s commute, then in any state X becomes a classical stochastic process. For example, $A + A^\dagger$ in the vacuum state $\Omega = \psi(0)$ is a classical standard Brownian motion. Similarly, $N_\lambda(t) = \Lambda(t) + \lambda^{1/2} [A(t) + A^\dagger(t)] + \lambda t$ determines the Poisson process with intensity λ in the vacuum state. By enlarging the Hilbert space $L_2[0, \infty)$ to $L_2[0, \infty) \otimes \mathbf{h}$, it is possible to construct all the classical processes with independent increments entirely in terms of the operators of creation, annihilation and conservation.

We say that an adapted process X is *simple* if

$$X(t) \equiv \sum_j X(t_j)\, \chi_{[t_j, t_{j+1})}(t)$$

where $0 = t_0 < t_1 < t_2 \ldots, t_n \rightarrow \infty$ as $n \rightarrow \infty$. If M is any one of the martingales A, $A^\dagger$, Λ, then we write

$$\int_0^t X(s)\, dM(s) = \sum_j X(t_j) [M(t_{j+1} \wedge t) - M(t_j \wedge t)]$$

where $a \wedge b$ denotes the minimum of a and b. If E, F, G, H are four simple adapted processes, we can then define the integral $\int_0^t (E\, dA^\dagger + F\, d\Lambda + G\, dA + H\, ds)$ by linearity, where ds indicates Lebesgue integral. It is possible to complete this integral and define adapted processes when E, F, G, H are not necessarily simple. Whenever H is identically zero, one obtains a martingale. It is a theorem that every martingale, under very general conditions is, indeed, of this form. Let

$$X_i(t) = X_i(0) + \int_0^t (E_i\, dA^\dagger + F_1 d\mathbf{\Lambda} + G_i\, dA + H_i\, ds), \quad i = 1, 2.$$

Then the following two identities hold :

$$\begin{aligned} \frac{d}{dt} &< \psi(f), X_1(t)\psi(g) > \\ &= <\psi(f), [\bar{f}(t) E_1(t) + \bar{f}(t) g(t) F_1(t) \\ &\quad + g(t) G_1(t) + H_1(t)] \psi(g) > \end{aligned}$$

$$\begin{aligned} \frac{d}{dt} &< X_1(t)\psi(f), X_2(t)\psi(g) > \\ &= < X_1(t)\psi(f), [\bar{f}(t) E_2(t) \\ &\quad + \bar{f}(t) g(t) F_2(t) + g(t) G_2(t) \\ &\quad + H_2(t)] \psi(g) > + < [f(t) E_1(t) \\ &\quad + f(t) \bar{g}(t) F_1(t) + \bar{g}(t) G_1(t) \\ &\quad + H_1(t)] \psi(f), X_2(t)\psi(g) > \\ &\quad + < E_1(t)\psi(f), E_2(t)\psi(g) > \\ &\quad + < E_1(t)\psi(f), F_2(t)\psi(g) > f(t) \\ &\quad + < F_1(t)\psi(f), E_2(t)\psi(g) > g(t) \\ &\quad + < F_1(t)\psi(f), F_2(t)\psi(g) > \bar{f}(t)\, g(t). \end{aligned}$$

The first identity reveals the martingale property whenever $H_i \equiv 0$. The second identity is the *quantum Ito's formula*, which can be summarized in the form of a multiplication table for quantum differentials :

	$dA^{\dagger}$	$d\Lambda$	dA	dt
dA	dt	dA	0	0
$d\Lambda$	$dA^{\dagger}$	$d\Lambda$	0	0
$dA^{\dagger}$	0	0	0	0
dt	0	0	0	0

In particular, $(dA + dA^{\dagger})^2 = dt$, which is the classical Ito's product formula for Brownian motion. If $N_{\lambda}(t) = \Lambda(t) + \lambda^{1/2} [A(t) + A^{\dagger}(t)] + \lambda t$, then $(dN_{\lambda})^2 = dN_{\lambda}$, which is the classical product formula for Poisson processes. Thus, in the quantum description, the classical formulae for products of Brownian and Poisson differentials reappear as a consequence of the commutation rules between the creation, annihilation and number operators.

As one of the many interesting applications of quantum stochastic calculus, we shall exhibit the fermion field operators in terms of the corresponding boson operators. To this end we introduce the reflection operators in $\Gamma(L_2[0,\infty))$ by

$$J(t)\,\psi(f) = \psi(-\chi_{[0,t]} f + \chi_{(t,\infty)} f),\quad f \in L_2[0,\infty).$$

Then J is a reflection valued adapted process. For any $\phi \in L_2[0,\infty)$ define the processes

$$F_{\phi}(t) = \int_0^t \bar{\phi}(s)\,J(s)\,dA(s),$$

$$F_{\phi}^{\dagger}(t) = \int_0^t \phi(s)\,J(s)\,dA^{\dagger}(s).$$

Then $F_{\phi}^{\dagger}(t)$ is adjoint to $F_{\phi}(t)$. If $F(\phi) = F_{\phi}(\infty)$, $F^{\dagger}(\phi) = F_{\phi}^{\dagger}(\infty)$, then $\{F(\phi),\ F^{\dagger}(\phi),\ \phi \in L_2[0,\infty)\}$ is an irreducible family of operators obeying the fermion canonical anticommutation relations

$$[F(\phi), F(\psi)]_+ = 0,$$

$$[F(\phi), F^{\dagger}(\psi)]_+ = \langle \phi, \psi \rangle$$

for all $\phi, \psi \in L_2[0,\infty)$.

Furthermore

$$F(\phi)\,\Omega = 0,$$

$$F^{\dagger}(\phi_1)\,F^{\dagger}(\phi_2)\ldots F^{\dagger}(\phi_n)\,\Omega = \int\limits_{0<s_1<s_2<\ldots<s_n<\infty} \det\,((\phi_i(s_j)))\,dA^{\dagger}(s_1)\ldots dA_i(s_n)\,\Omega$$

for all $\phi, \phi_1, \ldots, \phi_n \in L_2[0,\infty)$. These equations lead to a canonical unitary isomorphism between the fermion and boson Fock spaces over $L_2[0,\infty)$. Conversely, it is possible to express the boson annihilation and creation operators in terms of the corresponding fermion operators. Indeed,

$$a^{\dagger}(\phi_1)\ldots a^{\dagger}(\phi_n)\,\Omega = \int\limits_{0<s_1<\ldots<s_n<\infty} \mathrm{per}\,((\phi_i(s_j)))\,dF^{\dagger}(s_1)\ldots dF^{\dagger}(s_n)\,\Omega,$$

$$a(\phi) = \int_0^{\infty} \bar{\phi}(s)\,J(s)\,dF(s)$$

where $F(t) = F(\chi_{[0,t]})$ and per denotes the permanent of a matrix. These results can be extended in a natural manner to arbitrary dimensions as well as arbitrary temperature.

Quantum stochastic calculus provides a natural framework for studying Schrodinger equations in the presence of noise and integrating the Gorini-Kossakowski-Sudarshan-Lindblad equations. Consider the Hilbert space $\widetilde{H} = \mathbf{h}_0$

$\otimes\ \Gamma(L_2[0,\infty))$, where $\mathbf{h}_0$ is the initial Hilbert space of states of a quantum system and $\Gamma(L_2[0,\infty))$ is the Hilbert space of a 'heat bath'. Let U be a unitary operator valued adapted process satisfying a 'quantum stochastic differential equation'

$$dU = (L dA^{\dagger} + M dA + N dt)U,\ U(0) = 1$$

where L, M, N are adapted processes in $\widetilde{H}$. Quantum Ito's formula implies that $M(t) = -L^{\dagger}(t)$ and $N(t) = -i\ H(t) - \frac{1}{2} L^{\dagger}(t)L(t)$, where $H(t)$ is a self-adjoint operator valued process. When $L(t) \equiv 0$, the above stochastic differential equation reduces to the classical Schrodinger equation. It is a theorem that when $L(t) = L(0) = L$, $H(t) = H(0) = H$ are bounded operators, there exists a unique unitary operator valued adapted process U satisfying $dU = \{L dA^{\dagger} - L^{\dagger}\, dA - (iH + \frac{1}{2} L^{\dagger} L)\, dt\}U$, $U(0) = 1$. If X is any operator in the initial space, then $U^{\dagger}(t)\, X\, U(t)$ contracted to $\mathbf{h}_0$ via the vacuum Ω in $\Gamma(L_2[0,\infty))$ assumes the form $[\exp t\, \mathcal{L}](X)$, where

$$\mathcal{L}(X) = i[H, X] - \tfrac{1}{2}(L^{\dagger}LX + XL^{\dagger}L - 2L^{\dagger}XL).$$

It is to be noted that $\mathcal{L}$ is the generator of a quantum dynamical semigroup in the sense of Gorini-Kossakowski-Sudarshan-Lindblad.

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R Parthasarathy

A brief account of the major research achievements of Parthasarathy is given below.

A noncompact analogue of the Borel-Weil-Bott theorem was proved to give geometrical realizations of discrete class representations[1]. In another study[2], we used these results to extend the results of M S Narasimhan and K Okamoto [*Ann Math*, **91** (1970)] to *all* holomorphic discrete series. We proved that the multiplicity of integrable discrete classes in $L^2(G/\Gamma)$ equals the dimension of the space of harmonic spinors on $\Gamma\backslash G/G$ and this dimension is computed[3]. Some of the results of still another study[4] concern the structure of the restriction of discrete class representations of G to a maximal compact K. Under some hypothesis, the existence of a lowest K-type which occurs with multiplicity one is proved and also it is proved that the multiplicity of any K-type in a discrete class representation does not exceed the number given by Blattner's conjecture. 'Creation' and 'annihilation' operators were constructed using homological algebra methods to construct a representation of a semisimple Lie algebra[5]. These representations are shown to be unitarizable and Blattner's conjecture for discrete series and limits of discrete series associated to a Borel-de-Siebenthol chamber is proved.

In still another paper[6], to each parabolic subalgebra of the complexification of a real semisimple Lie algebra, stable under a Cartan involution, a class of representations is constructed. Their infinitesimal description based on the theory of Verma modules parallels that of finite dimensional modules. In each member of this class, a special irreducible K-type occurring with multiplicity one is exhibited along with an explicit description of the action, on this K-type, of the centralizer of K in the enveloping algebra of G. The problem of characterizing the unitary dual G, beyond the ones which occur in the Plancherel formula, is the most challenging and unsolved problem in representation theory. An important subclass of G is the unitary highest weight modules. For a long time only partial results of Harish-Chandra, N Conze and N Wallach were available. Known results were few and even conjecturally no one had an idea of what this subclass should be. In one of our papers[7], we give a complete description of the unitary highest weight modules with nonsingular infinitesimal character. The notion of a 'lattice of g-modules' was defined by T Enright. To each object W of a category, which is like the B-G-G category, the end object $\tau(W)$ associated via the lattice is a Harish-Chandra module. We associate to each member of a reasonably large class of

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hermitian (resp. contravariant) forms on W a hermitian (resp. contravariant) form on each member of the lattice and a form on $\tau(W)$. The main result is that 'invariant' forms go to invariant forms[8]. We give a decomposition of the space of holomorphic forms in $\Gamma\backslash G/K$ and study multiplication of these forms with the Chern classes of some natural bundles on $\Gamma\backslash G/K$ in one paper[9]. In the special cases considered, these results seem to be generalizations of Lefshetz decomposition theorem for compact Kähler manifolds. By tensoring the Weil representation and decomposing, M Kashiwara and M Vergne have obtained a family of unitarizable highest weight modules for $U(p,q)$ and $Mp(n,IR)$. We settled the conjecture of Kashiwara and Vergne, namely, that their list exhausts all unitarizable highest weight modules for these groups[10]. 'Multiplicities' in the induced representations, of which only the 'harmonics' are identified by the Borel-Weil-Bott theorem and its noncompact analogue, are shown to obey a certain reciprocity[11], thus relating the compact case to the noncompact case. In two of our other papers[12,13], the unitarizability of certain representations of a semi-simple Lie algebra are proved. At another place[14], it is shown that all the non-degenerate t-structures in the derived category of representations of a quiver corresponding to Dynkhin diagrams are obtained by using composites of Gelfand-Ponomarev reflection functors.

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*The numbers within square brackets at the end of some references denote the review numbers in *Mathematical Reviews*.

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B L S Prakasa Rao

Let X_1, X_2, …, X_n be independent and identically distributed observations from a population with distribution function $F(.)$. A major problem of interest in statistical inference is to estimate $F(.)$ based on the observed sample. If the functional form of $F(.)$ is known but for a parameter, then the problem is called parametric; otherwise it is said to be non-parametric. Suppose that the distribution function F has a density f which is unknown. The basic asymptotic distribution theory for a modified maximum likelihood estimator of f was obtained by Prakasa Rao, when the density f is unimodal[1] and when the density f has a monotone failure rate[2]. Under some regularity conditions, it was shown that the scale factor for obtaining the limiting distribution is $n^{1/3}$ and not $n^{1/2}$, as in the classical case of parametric inference. The problem of determining the limiting distribution explicitly still remains an open problem. The classical theory of maximum likelihood estimation of a parameter θ of a density $f(.,\theta)$, as developed by Cramer, is not applicable if the density is not differentiable, for instance, for density of the form $f(x,\theta) = e^{-\frac{1}{2}|x-\theta|}$ The asymptotic distribution theory for maximum likelihood estimators in non-regular problems of this type was given by Prakasa Rao[3]. The technique used is to consider the likelihood ratio as a stochastic process in the parameter θ and obtain the limiting distributions through the theory of weak convergence for stochastic processes. It was shown that the maximum likelihood estimators are hyper-efficient in the non-regular case unlike the situation in the regular case. In view of the importance and potential applications in engineering and the other applied sciences, it is necessary to study whether the classical results in statistical inference extend to dependent random variables or in other words for stochastic processes. This has been done in a series of papers. The classical Bernstein-von Mises theorem concerning the convergence of posterior density to normal density in L_1—mean has been proved by Borwanker, Kallianpur and Prakasa Rao[4] when the observations were from discrete time stationary Markov processes. The rates of convergence and bounds on the difference between Bayes and maximum likelihood estimators were also obtained. Maximum likelihood estimation (MLE) for Markov processes and the rate of convergence of the distribution of minimum contrast estimator, which generalises MLE was discussed by Prakasa Rao[5]. The theory of maximum likelihood estimator for general stochastic processes was developed by Besawa and Prakasa Rao[6]. Non-parametric density estimators both sequential and fixed sample type for

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discrete time as well as continuous time stationary Markov processes were studied and Berry-Essen type bounds for the convergence of the distribution function of a density estimator of kernel type were obtained. Another area where parametric and non-parametric inference problem has been studied is the estimation of drift coefficient for a class of diffusion processes. Asymptotic theory of estimation in non-linear stochastic differential equations has been discussed by Prakasa Rao and Rubin[7] and Prakasa Rao[8] and asymptotic properties of least squares estimators for such processes have been derived. Bernstein-von Mises theorem was extended to a class of diffusion processes by Prakasa Rao[9] and, as a consequence, the properties of Bayes estimators were derived for such processes. Some of these results concerning statistical inference for stochastic processes were discussed by Basawa and Prakasa Rao[6] and the theory of non-parametric functional estimation was surveyed by Prakasa Rao[10]. Recently, the asymptotic theory of least squares estimation (LSE) was developed through the theory of weak convergence by considering the sum of square deviations as a stochastic process in the parameter. This approach is likely to bring out more useful and interesting results as the approach to the asymptotic theory of MLE via the likelihood ratio process did. This method was used by Prakasa Rao[11] to study the limiting distribution of LSE in a non-linear regression model of the type:

$$Y_i = | x_i - \theta |^{\lambda} + \epsilon_i, \; i \geqslant 1.$$

In the course of the work on parametric and non-parametric asymptotic theory of statistical inference for stochastic processes, it was necessary to study limit theorems in probability for dependent random variables which are of independent interest.

Prakasa Rao's contributions to the theory of probability have been in the areas of characterization problems and limit theorems in probability. An analogue of Bochner's theorem for infinitely divisible characteristic functionals on Hilbert spaces, locally convex spaces and locally compact abelian groups was obtained. A survey of results characterizing stochastic processes through stochastic integrals was made by Prakasa Rao[12]. Prakasa Rao and Ramachandran[13] obtained a characterization of systematic stable processes using Choquet-Deny theorem. Random central limit theorem for martingales, limit theorems for reverse martingales, rates of convergence in the invariance principle for random sums[14] and non-uniform rates of the convergence in the central limit theorem for *m*-dependent random fields are some of the areas to which contributions were made. Tightness probability measures generated by stochastic processes indexed by parameter in a metric space with application to random Fourier series were given by Prakasa Rao[15]. Stability problems for the solution of stochastic integro-differential system were studied in a series of papers.

A major and important problem which has not been studied intensively up to now and which needs investigation is the statistical inference for random fields. Loosely speaking, let us suppose that we have a stochastic process $\{X_{(s,t)}, (s,t) \epsilon R \times R\}$ and suppose that the process is determined by a parameter θ in the sense that the finite dimensional distributions of the process are completely known, given the parameter θ. One problem is to devise a method to sample the observations in order to get a "best" estimator for θ in a specified sense. Can we obtain a maximum likelihood estimator for θ, and what are its properties? Can the theory developed for stochastic processes with index in R extend to higher dimensions? Such results are of potential use in the study of forest management (to detect spread of infection among the trees) or in spatial data analysis (to detect or estimate national resources from data observed through satellite photographs, etc.). Apart from the importance and practical interest in the problems, they will also lead to problems of independent interest in probability theory for random fields as the recent developments in the theory of martingales with two-dimensional parameter did.

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*The number at the end of some of the references denotes the review number in *Mathematical Reviews*.

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C Radhakrishna Rao

The contributions of Radhakrishna Rao cover several areas of statistical theory and applications.

Estimation

Rao[1] established that the variance of an unbiased estimator of a parameter θ is not less than $1/I(\theta)$, where $I(\theta)$ is Fisher information on θ contained in a sample, which is known as Cramer-Rao inequality. It was also shown that given any unbiased estimator, one can construct a function of sufficient statistics which is unbiased and has possibly a smaller variance than that of the given estimator, a process known as Rao-Blackwellization. Using the Fisher information matrix, a quadratic differential Riemannian metric (known as Rao metric with the associated Rao distance) is introduced in the space of probability distributions. Rao's early paper[1] dealt with the application of differential geometry in statistics, which is being actively pursued at present.

Fisher defined the efficiency of an estimator as its asymptotic variance. But there exists a wide class of estimators having the same asymptotic variance or efficiency (called the first order). To distinguish among them, the concept of second order efficiency was introduced by Rao[2]. One of the results in this study known as Fisher-Rao theorem provides an expression for maximal second order efficiency. Under some conditions, it is shown that the maximum likelihood estimator of a parameter in a multinomial distribution has the highest second order efficiency.

Rao[3] introduced a new principle known as MINQE (minimum norm quadratic estimation) for the estimation of variance components in linear models. Explicit expressions were obtained for MINQE's under additional conditions, such as unbiasedness, invariance and non-negativeness of an estimator.

A unified theory of linear estimation in the general Gauss-Markoff model without any assumptions on the design and error covariance matrices is developed. Three approaches were suggested[9]: generalized inverse partitioned matrix method, unified least squares theory, and geometric method through a generalized projection operator.

Asymptotic Tests

Score and Lagrangian multiplier tests based on large samples were developed by Rao[4] to test simple and composite hypotheses under very general conditions. Recent studies show that these tests have better local optimum properties compared to other competing tests, such as likelihood ratio and Wald's tests.

Characterization of Probability Distributions

A number of characterizations of the

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normal, Poisson, Cauchy, stable, exponential, geometric and other distributions were obtained based on the properties of sample statistics. The results were presented in the book by Kagan, Linnik and Rao[5]. An interesting result which has led to considerable research by a number of workers is the characterization of the Poisson distribution through what is called Rao's damage model and the Rao-Rubin condition[6]. This study also led to an extension of Deny's theorem on the solution of an integrated Cauchy functional equation and its application to numerous characterizations of the exponential, geometric and Pareto distributions[7]. A general class of distributions known as weighted distributions were introduced by Rao[6], which have received several practical applications.

Matrix Algebra

The problem of defining a generalized inverse (g-inverse) of a singular square or rectangular matrix, or a general linear operator, was studied by Rao[8,9]. It was shown that different classes of g-inverses can be defined for use in different problems, such as solving consistent equations, finding minimum norm solutions, computing least squares solutions of inconsistent equations, etc. An explicit expression for the projection operator onto the space spanned by the column vectors of a matrix X is given in terms of a generalized inverse, $X(X X)^{-} X'$, which is now widely used in the discussion of linear models. A geometric approach leading to very general results was discussed by Rao and Yanoi[10]. G-inverses have received wide applications.

The concept of a projection operator on a subspace along a disjoint but not necessarily a complementary subspace was developed and used in providing a unified theory of linear estimation of parameters in a general Gauss-Markoff model. Explicit expressions were obtained for such projection operators.

Multivariate Analysis

In multivariate analysis, one usually faces the problem of extracting information from a large number of measurements $x_1, x_2, \ldots$ made on each sample unit or individual. Not all measurements carry independent information, and paradoxical situations arise where procedures based on a subset of measurements are more efficient than those based on the whole set. A question that arises then is whether the information in a given subset of measurements $(x_1, \ldots, x_p)$ is the same as that in the whole set $(x_1, \ldots, x_p, \ldots, x_{p+q})$ for answering a particular problem. In such a case, the set of measurements $x_{p+1}, \ldots, x_{p+q}$ becomes redundant. A test for this hypothesis known as Rao's U test was developed by Rao[11].

The use of canonical variates (coordinates) in the representation of higher dimensional data in a lower dimensional space was discussed by Rao[12]. This is a useful device in studying clustering and inter-relationships among individuals or populations.

Analysis of Diversity

Using general diversity measures applicable to both qualitative and quantitative data, analysis of diversity was developed as a generalization of analysis of variance. The limitations of some of the well-known entropy functions (such as Shannon's) as measures of diversity were discussed. A new measure referred to as

Rao's quadratic entropy was introduced and its usefulness in analysis of diversity demonstrated[13,14]. Further work on these lines using the concept of cross-entropy is being pursued.

Combinatories

Combinatorial arrangements known as orthogonal arrays were introduced in Rao[15] for use in design of experiments. These arrangements are being used widely in multifactorial experiments to determine optimum combinations of factors in problems of production. These arrangements have applications in coding theory, a result of practical interest being the Hamming-Rao bound associated with orthogonal array.

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S Raghavan

We have been principally interested in number theory and the theory of automorphic forms with applications to analytic number theory, especially the analytic theory of quadratic forms.

One of the earliest questions which seem to have fascinated number theorists is that of the representability of a given natural number n as a sum of, say, t squares of integers and finding a formula for the number $r(n;t)$ of ways of thus representing n. For low values of t, such a formula does exist, involving *elementary* arithmetical functions of n, such as divisor functions, but, due to technical reasons, it is hard, in general, to obtain an exact formula for $r(n;t)$ for any given t. Using a powerful analytical technique known as the 'circle method', Hardy and Ramanujan in 1918 discovered, for $t > 4$, an 'asymptotic' formula, viz. $r(n;t)$ equals an arithmetical function $s(n;t)$ for all large n, up to an error of order $n^{t/4}$. Hecke derived their formula, in 1928, by invoking the profound theory of modular forms. A standard generating function for $r(n;t)$ is a theta series, while $s(n;t)$ turns out to be the general Fourier coefficient of an Eisenstein series; both these objects, in their own right, serve as 'building blocks' for modular forms and functions and a special identity now referred to as the Siegel formula links these two apparently totally disparate objects, so that it was not entirely fortuitous for $s(n;t)$ to approximate to $r(n;t)$. Now, instead of looking for the representability of n by the quadratic form $x_1^2 + \ldots + x_t^2$, one can, more generally, ask for a formula for the number $R(F;G)$ of integral representations of an integral positive definite quadratic form F in r variables by another such form G in $m(\geqslant r)$ variables. Using Siegel's deep analytical techniques including a 'generalized circle method' in the theory of modular forms of degree r, estimates for the Fourier coefficients of such modular forms were obtained[1] and in particular, an asymptotic formula for $R(F;G)$ generalizing the Hardy-Ramanujan formula was derived, with natural technical restrictions. Analogous results for hermitian modular forms and a proof of Siegel's main theorem for indefinite hermitian forms constituted the themes of another paper[2]. In 1978, a remarkable contribution to the estimation of Fourier coefficients of Siegel modular forms came from Kitaoka; using his ideas as well as methods of Klingen and Hel Braun, estimates for Fourier coefficients of modular forms of arbitrary stufe could be improved further[3]. An explicit construction of cusp forms of degree 2, weight 3 and level 2 is furnished in another paper[4], answering a question raised by Freitag; construction of cusp forms from theta series with spherical harmonics is also discussed here.

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From Kronecker, we know that the values, at integral arguments, of an irrational linear form (e.g. $ax + v$ for an irrational number a) are dense. In a series of important papers, Davenport (with Birch and Ridout) showed that, for an irrational indefinite quadratic form f in $n > 20$ variables, the values at integral arguments are dense near 0; Davenport's conjecture is that this phenomenon holds even for $n > 4$. Replacing integers by algebraic integers in a number field K as is customary in such questions, it was shown[4] that when f (as above) is a 'zero form', then, for $n > 4$, its values (at algebraic integral arguments) are dense; an analogue of Davenport's theorem for 'large' n, depending also on the degree d of K, was proved[5]. A question of a similar nature replacing f by an irrational form of additive type in n variables was resolved[6] with an *n independent* of d. For indefinite quadratic f of 'small signature', a quantitative twist to Davenport's theorem was provided[7]. Bounds for minimal zeros of quadratic forms, similar to Cassels', over number fields, were given in another paper[8].

In the same spirit as Kronecker's result above, orbits of 'irrational' euclidean frames under familiar discrete groups were shown to be dense[9]; this has since been vastly generalized by Dani. An adelic analogue of a theorem of Khintchine on the solvability in integers, of inequalities arising from systems of linear forms and a quantitative version of Kronecker's theorem dealing with bounds for integral euclidean frames occurring as solutions of an 'irrational' system of linear inequalities are contained in one paper[10].

In the case of modular forms of degree $n > 1$, Hecke's Grenzprozess applied to the analytic continuation of Eisenstein series was considered by Siegel as capable of yielding holomorphic modular forms, unlike in the case $n = 1$. The first such non-trivial case $n = 3$ was exhibited[11] in support of his conjecture, giving rise indeed to a theta series. The general case has since been resolved by Shimura and Weissauer, using, however, Langlands' deep results.

Theta series, as mentioned, have been, in general, expected to generate modular forms of degree n (and weight divisible by 4). The fulfilment of this (hope) at least for 'singular' modular forms was demonstrated[12] independently of Freitag and Resnikoff. A recent beautiful work of Bocherer greatly substantiates this expectation.

The explicit connection between zeta functions of indefinite quadratic forms investigated by Siegel and then, in an adelic set-up by Weil, was clarified[13]. A generalization of a Poisson formula due to Yamazaki (via the Mellin transform) so as to include Dirichlet series with functional equations accommodating multiple gamma-factors and thereby Maass' (non-analytic automorphic) 'wave forms' (and also covering an adelic version) was proved[14] following the ideas of Igusa.

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M S Raghunathan

Almost all my work has been in the general area of linear algebraic groups and discrete subgroups of Lie groups. A linear algebraic group is a subgroup of $GL(n)$, which is in addition an algebraic variety. If as a variety it is the set of zeros of polynomials with coefficients in a given field k, the algebraic group is said to be defined over k or simply called a k-group. If k is a number field and O its ring of integers and $G \subset GL(n)$ is an algebraic k-group, a subgroup $\Gamma \subset G(k) = G \cap GL(n,k)$ is called an arithmetic group if $\Gamma \cap GL(n,O)$ has finite index in Γ as well as $G(O) = G \cap GL(n,O)$. When k is Q, such a Γ is a discrete subgroup of the Lie group $G(\mathbf{R}) = G \cap GL(n,\mathbf{R})$. A theorem of Borel and Harish-Chandra assertstha $k = Q$) if $G = [G,G]$, $G(\mathbf{R})/\Gamma$ has finite Haar measures. A converse to this was an open problem which attracted considerable attention. Some of my work related to this problem is certainly among my best contributions. I first showed that when $G(\mathbf{R})/\Gamma$ is *not compact* Γ is rigid in some suitable sense. This was an extension of the results of A Weil on the cohomology of discrete subgroups of Lie groups with compact quotients. Subsequently, I could establish the sought after converse again under the hypothesis that $G(\mathbf{R})/\Gamma$ is non-compact (G A Margulis had independently obtained the same results by different techniques a little earlier; his work was, however, not available to the mathematical public at that time; a few years later, he proved the converse in complete generality using very striking and original ideas which led to his being awarded the Field's medal.)

Another question related to arithmetic groups where my contributions may be considered significant is the "Congruence subgroup problem". The problem here is to determine all normal subgroups of $G(O)$, k and O being as described above. Here, the best available and practically complete solutions were obtained by me partly in collaboration with G Prasad. Under certain conditions of G (which one knows are necessary) the main result is that if $N \subset G(O)$ is a normal subgroup of $G(O)$, one can find an ideal $a \subset O$, $a \neq O$ such that N contains a subgroup of $G(O)$ of the form $[\Gamma,\Gamma)$, where Γ is the group

$$\{x \epsilon G(O) \mid x \equiv 1 (\mathrm{mod}\ \ a)\}$$

and $N/N \cap \Gamma$ is isomorphic to a subgroup of $\mu(k)$, the group of roots of unity in k. The work on the congruence subgroup problem was initiated by Bass-Serre-Lazard, but their methods could handle only special cases. The ideas introduced by me in the so-called rank-1 case, I believe, are significant.

The complete solution of the congruence subgroup problem (for

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isotropic G) depends on some cohomology computations for locally compact groups of the form $G(k)$, k being a local field. The computation of the second cohomology groups of $G(k)$ with coefficient in $\mathbf{Q}/\mathbf{Z}$ is an interesting piece of work which I did in collaboration with G Prasad.

Selected Publications

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10. Raghunathan M S & Gopal Prasad, Tame subgroup of a semisimple group over a local field, *Am J Math* (1982) 1023-48.
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13. Raghunathan M S & Gopal Prasad, On the congruence subgroup problem, *Invent Math*, **71** (1983) 21-42.
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K Ramachandra

Analytic Theory of Numbers

(1) *Complex Multiplication*: E E Kummer proved that if $p \geqslant 5$ is any prime number and $\zeta = \text{Exp}\left(\frac{2\pi i}{p}\right)$, then the units $\frac{1-\zeta^2}{1-\zeta}$, $\frac{1-\zeta^3}{1-\zeta}, \ldots, \frac{1-\zeta^a}{1-\zeta}$ $\left(\text{where } a = \frac{p-1}{2}\right)$ are multiplicatively independent. This result was generalized to the case where p was replaced by any composite number $n \geqslant 5$ by Ramachandra[1]. These units are related to abelian extensions of the rational number field. In the case of abelian extensions of an imaginary quadratic field, we encounter (in place of the exponential function) the modular functions

$$\Delta_g(z) = q^{\lambda} \prod_{n=-\infty}^{\infty} (1 - q^{\mu})^{12g}$$

where $g > 1$ is an integer; $\lambda = g - 6 + \frac{6}{g}$, $\mu = |\, n + \frac{1}{g} \,|$ and $q = \text{Exp}\,(2\pi i\, z)$ with $Im\ z > 0$. Using the singular values of these functions, Kummer's formulae were generalized to cover the units of an abelian extension of an imaginary quadratic field by Ramachandra[2]. In the same paper, he used a device due to S Ramanujan to study the singular values of modular forms and their derivatives.

(2) *Approximation of Algebraic Numbers*: Let α be a fixed algebraic number of degree g; and ζ, a variable algebraic number of height $H(\zeta)$ and of fixed degree h. Let μ be fixed to exceed the minimum (as m ranges over all positive integers) of the expression $m\, h^{m-1} \left(\frac{g}{m!}\right)^{1/m}$. Improving a result of C L Siegel, Ramachandra[3] proved that if $\zeta \neq \alpha$, then the inequality

$$|\alpha - \xi| < (H(\zeta))^{-\mu}$$

is satisfied by at most finitely many algebraic numbers. (This result was proved independently by A Baker. Soon afterwards, this result was improved by E Wirsing and W M Schmidt, who relaxed the condition on μ to $\mu > 2h$ and $\mu > h + 1$ respectively). K Mahler investigated some lattice point problems and in particular proved that the number of lattice points (x,y) in the region $|x^3 - 2y^3| \leqslant X$ is $\sim CX^{2/3}$. Using the result stated above, Ramachandra extended this result to several variables.

(3) *Transcendental Numbers*: Some general questions on transcendental numbers were investigated by Ramachandra[4]. (These were investigated independently at the same time by S Lang.) A special case is as follows. Let a and b be any two fixed complex numbers, such that a/b is irrational. Then the set of complex numbers z such that both Exp(a

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z) and Exp(b z) are algebraic is a vector space over the rationals of dimension $\leqslant 2$. As a corollary to this result it was deduced by Ramachandra that if t be any fixed transcendental number, then the number of algebraic numbers amongst $2^{t}, 2^{t^2}, \ldots, 2^{t^N}$ is $0(\sqrt{N})$. This result is new.

(4) *Baker's Methods*: Results on the linear forms in the logarithms of algebraic numbers due to A Baker were adopted to various situations. Especially when the number of variables in the linear form was large, the results were new. The results were applied to Grim's problem and gaps between numbers with a large prime factor. Let $k \geqslant 3$ be a fixed integer and let $n_1, n_2, \ldots$ be the sequence (in the increasing order) of all natural numbers which have at least one prime factor $> k$. Then the maximum gap $n_{i+1} - n_i$ is, for $k \geqslant 100$,

$$0\left(\frac{k \log\log\log k}{\log k \log\log k}\right).$$

This work is a joint effort of K Ramachandra, T N Shorey and M Jutila[5].

(5) *Riemann Zeta-Function*: Several important results on the Riemann zeta-function were proved. They deal with the mean-value of the Titchmarsh series, mean-value of the Riemann zeta-function, the zeros of the Riemann zeta-function and Ω theorems for $|\zeta(s)|$ in $\frac{1}{2} \leqslant \sigma \leqslant 1$. We now state a few special cases of the results proved. Let $100 \leqslant \log\log T \leqslant H \leqslant T$. Then

$$\frac{1}{H} \int_{T}^{T+H} \left|\xi^{(l)}\left(\tfrac{1}{2} + it\right) dt \gg (\log H)^{1/4+l},\right.$$

$$\frac{1}{T} \int_{T}^{2T} \left|\xi^{(l)}\left(\tfrac{1}{2} + it\right)\right| dt \ll (\log T)^{1/4+l},$$

$$\underset{T<r<T+H}{\text{maximum}} \left|\zeta\left(\tfrac{1}{2} + it\right)\right| >$$

$$\operatorname{Exp}\left(\frac{3}{4}\left(\frac{\log H}{\log\log H}\right)^{1/2}\right), \; H \geqslant H_0.$$

The result on the zeros is an improvement over that of H L Montgomery. It is complicated to state. Some of these results are due to the joint efforts of K Ramachandra and R Balasubramanian[6–8].

(6) *Goldbach Problem*: Let $y = x^{\lambda}$, $z = x^{\mu}$, where $\lambda > \frac{7}{12}$ and $\mu > \frac{7}{72}$ are fixed. It was shown that the number of Goldbach numbers of satisfying $x \leqslant g \leqslant x + y$ is $\sim \frac{1}{2} y$ and the number of Goldbach numbers satisfying $x \leqslant g \leqslant x + z$ is $\gg z$. The second result is an improvement over a result of H L Montgomery and R C Vaughan (for some references, see reference 9).

(7) *Zeros of a Class of Generalized Dirichlet Series*: Several papers were written on this subject, some of them jointly by K Ramachandra and R Balasubramanian. We state a special case of one of the results[10]. Let $a_1, a_2, \ldots$ be a bounded sequence of complex numbers with $\sum_{n \leqslant x} x\, a_n = 0(x^{\theta})$, where $0 \leqslant \theta < \frac{1}{2}$. Put $L(s) = \zeta(s) + \sum_{n=1}^{\infty} (a_n n^{-s})$. Then the number of zeros of $L(s)$ in $\sigma > \frac{1}{2} - \delta$, $|t| \leqslant T$ is $\gg T \log T$, if $\theta = 0$, and $\gg T \log T (\log\log T)^{-1}$ otherwise.

(8) *Diophantine Approximation*: Let $\lambda_1, \lambda_2, \lambda_3$ be fixed non-zero real numbers (not all of the same sign) which are not in rational ratios. Let $X \geqslant 100$ and let $m(X)$ denote the minimum of the expression $|\lambda_1 p_1 + \lambda_2 p_2 + \lambda_3 p_3|$ as p_1, p_2, p_3 run over all triplets of primes subject to $p_1 + p_2 + p_3 \leqslant$

X. Then Ramachandra proved that

$$m(X) < \mathrm{Exp}(-c(\log X)^{1/2}).$$

Ramachandra also obtained more general results[11]. (These results are improvements over the earlier results of W Schwarz and A Baker. Ramachandra's results have been improved further by R C Vaughan).

(9) *Some Problems of Analytic Number Theory*: Ingham's and Selberg's prime number theorems for primes in short intervals were generalized. Omega theorems in asymptotic formulae were systematized. These results came from (a) the singularities of the generating functions, and (b) the growth of the generating functions[12]. Problems involving both the complications (a) and (b), such as the problem of k-full numbers, were solved successfully. Some of these results were worked out with the collaboration of K Ramachandra, R Balasubramanian and M V Subbarao.

(10) *Asymptotic Formulae*: Asymptotic formulae in additive number theory connected with sequences defined by divisibility properties were proved. Gaps in sequences defined by divisibility properties were investigated. Some of these results were investigated with the collaboration of K Ramachandra, P Erdös, G Jogesh Babu and M J Narlikar[13].

(11) *Miscellaneous Work*: An elementary proof of Siegel-Tatuzawa theorem was given[14]. An obituary of V Brun was written and here a novel exposition of Brun's method was given[15].

Selected Publications

1. Ramachandra K, On the units of cyclotomic fields, *Acta Arith*, **12** (1966) 165-73.
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7. Ramachandra K, Some remarks on the mean-value of the Riemann zeta-function and other Dirichlet series-III, *Ann Acad Sci Fenn*, **AI, 5** (1980) 145-58.
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11. Ramachandra K, On the sums $\sum_{j=1}^{k} \lambda_j f_j(p_j)$, *J Reine u Angew Math*, **262/263** (1973) 158-65, **264** Addendum 202.
12. Balasubramanian R & Ramachandra K, Some problems of analytic number theory-III, *Hardy-Ramanujan J*, **4** (1981) 13-40.
13. Babu G J, Erdös P & Ramachandra K, An asymptotic formula in additive number theory-II, *J Indian math Soc*, **41** (1977) 281-91.
14. Ramachandra K, One more proof of Siegel's theorem, *Hardy-Ramanujan J*, **3** (1980) 25-40.
15. Ramachandra K, Viggo Brun (13-10-1885 to 15-8-1978), *Math Student*, **49** (1981) 87-95.

S Ramanan

My research contributions have been in the following areas of mathematics: Differential geometry, Homological algebra, Invariant theory, and Algebraic geometry.

Differential Geometry

My main result here (obtained in collaboration with M S Narasimhan) is the existence of universal connections for principal bundles with a given Lie group as the structure group. This is on the analogy of the topological classification theorem which asserts that any such principal bundle is induced by a continuous map into a fixed 'classifying space'. The universal bundle and the classifying space may be taken to be the natural bundle on the Grassmannian in the case when the group is the unitary group. The universal connection mentioned above can be taken to be the natural homogeneous connection in this case. This result proved to be of use much later in the Chern Simons theory of secondary characteristic classes on the one hand and more surprisingly in the Gauge theories on the other in recent years.

I have been writing a book on the formal aspects of differential operators and their symbol calculus. These serve to clarify the role of what is the known as the Weizenbock formula in the various vanishing theorems.

Homological Algebra

Early in my career, I computed the global dimension of some associative algebras arising from Lie algebras.

Invariant Theory

I contributed to a conceptual understanding of what are known as Capelli's identities. My ideas led to the proof by Carter and Lusztig of the linkage principle which gives a necessary condition for two $GL(n)$-modules to occur as Jordan-Holder factors of the same indecomposable module. More recently, I studied (in collaboration with A Ramanathan) the parabolic group 'responsible for the instability of a point' under a reductive group action over non-perfect fields.

Algebraic Geometry

This has been the principal area of my research during the last 20 years. The modern study of vector bundles over compact Riemann surfaces (or projective non-singular curves over arbitrary fields) commenced around the mid-sixties. The key idea due to Mumford is the notion of stable and semi-stable bundles arising from geometric invariant theory. In the programme of a systematic investigation of the properties of moduli space of semi-stable bundles, I have proved, both individually and in collaboration with

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colleagues, many basic results. The moduli space of bundles of rank 2 have been, naturally, the ones extensively studied. A nonsingular model for these was obtained after an initial geometric insight was provided by the genus 2 case. A complete classification was given in the case of hyperelliptic curves. As for the moduli space of bundles of rank $\geqslant 3$, the singularities were determined; the deformations of these spaces have been computed. From the conceptual angle, I showed that a Poincaré bundle, namely, a bundle which is universal for families of stable bundles, exists if and only if the degree and the rank of the bundles concerned are relatively prime. Recently, the applications of the concept and results regarding stable bundles to other geometric problems have been engaging my attention. One such surprising application is that the (non-hyperelliptic) Kummer 3-fold can be defined by cubic equations — a classical problem not accessible to traditional methods. Another possible application could be in the study of the canonical homogeneous ring of a curve.

I have also been interested in homogeneous varieties, such as the flag manifold, Grassmannians, etc. I had shown in my thesis that homogeneous vector bundles are stable and that many of them admit non-trivial deformations. I also settled (in collaboration with A Ramanathan) the question of projective normality of ample line bundles on flag varieties as well as Schubert varieties.

My recent results in algebraic geometry include the complete determination of divisors on Abelian surfaces that are very ample, throwing light on the Horrocks-Mumford bundle on 4-dimensional projective space and the existence (or otherwise) of Poincaré bundles for line bundles for families of curves. This latter result (obtained in collaboration with N Mestrano) includes the cases of the generic curve of genus g, the generic plane curve and the generic hyperelliptic curve as examples.

Selected Publications

Differential geometry

1. Ramanan S & Narasimhan M S, *Existence of universal connections, Am J Math*, **83** (1961) 563-72.
2. Ramanan S & Narasimhan M S, Existence of universal connections. II, *Am J Math*, **85** (1963) 223-31.

Homological algebra

3. Ramanan S, On the global dimension of some algebras, *Math Z*, **81** (1963) 392-94.

Invariant theory

4. Ramanan S, *Capelli's identities*, preprint and circulated as an extract from a letter to **M F** Atiyah, 1971.
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15. Ramanan S & Ramanathan A, Projective normality of flag varieties and Schubert varieties, *Invent Math*, **79** (1985) 217-24.
16. Ramanan S, Ample divisors on Abelian surfaces, *Proc Lond math Soc*, **51** (1985) 231-45.
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N Rudraiah

Rudraiah is a specialist in fluid mechanics and allied fields. He has developed a school of fluid mechanics in the Bangalore University. More than 20 students have obtained PhD degree under his guidance and he and his students have authored over 150 research papers.

The areas in fluid mechanics in which Rudraiah is interested include: (i) Hydrodynamic and hydromagnetic stability, (ii) Exact solutions of MHD generators and lubrication, (iii) Internal gravity waves, (iv) Flow through and past porous media, (v) Biomechanics, and (vi) Convection problems. In each of these areas, he has made significant contributions to knowledge. For instance, he studied the effects of magnetic field on stratified conducting fluid as early as in 1960's and proved a semi-circle theorem. His early work on stratification was concerned with layer-layer stratification and his later work was on the stability of stratification due to buoyancy. He is now interested in studying non-linear and Coriolis effects on the stability of stratified fluids. He has made use of regular and singular perturbation techniques to get some exact solutions of MHD with applications to MHD pumps, generators and lubrication and has developed a mathematical model for MHD power generators based on indigenous materials. His work on MHD lubrication includes both slider and journal bearings. His early work on linear internal gravity waves was concerned with the effects of magnetic field and Coriolis force wherein he identified a 'valve' effect in the compressible atmosphere and made a detailed analysis of 'critical level' behaviour. He is at present working on non-linear internal Alfven gravity waves using 'phase portrait' analysis and 'power integral' method and he proposes to make a detailed study of non-linear critical level behaviour.

Rudraiah has developed a non-Darcy flow model for porous media by incorporating, in addition to the usual inertia term and the usual viscous shear due to distortion of velocity, an inertia represented by a drag with quadratic dependence on velocity in a sparsely packed porous medium. Using this model, he and his collaborators have studied extensively the single-, two- and multi-component convection through vertical, horizontal and inclined porous media with and without the external constraint of rotation. Work is in progress to include non-uniform properties of the medium, turbulent and cross-diffusion effects on convection employing power integral technique, modal analysis, spectral and other numerical methods. In his studies on flow past a porous medium, he has formulated a new 'slip boundary' condition

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by incorporating the (finite) thickness of the porous layer; this condition includes the classical Beaver and Joseph slip condition as a limiting case. He has considered some important problems on stability which reveal interesting phenomena characterizing this new condition. He has developed a mathematical model for studying dispersion in a porous medium with bio-mechanical applications by generalizing the well known Taylor dispersion model. While the Taylor model is applicable only under quasi-steady condition, the dispersion model formulated by him is applicable in more general situations.

His studies on Marangoni convection under microgravity environment have potential applications in the modelling of single crystal growth processes, semiconductor devices and metallurgical processing. He is at present interested in nonlinear Marangoni convection, which includes the effects of surface tension, crystalline anisotropy, non-equilibrium solidification and convection in the melt.

His work on non-linear magnetoconvection has attracted the attention of many astrophysicists who have employed his model to explain the 'super-granulation' phenomenon. He has predicted the effect of magnetic field and rotation on heat transfer and is at present interested in non-linear magneto-diffusive convection using parametric differentiation, spectral analysis and power integral methods.

His studies on heat transfer in a totally enclosed fan-cooled motor and eddy current losses in electric transformers have a direct bearing on industrial problems. He has done this work as a consultant to the New Government Electric Factory, Bangalore.

Some of the areas in which Rudraiah and his students propose to work in the near future are: (i) chaotic motions in convection through porous media and the application of the bifurcation theory thereon, (ii) Steady and transient combined Rayleigh-Bernard-Marangoni convention, (iii) Applications of infinitesimal transformation and spectral analysis to flow through porous media. Preliminary work in each of these areas is in progress.

Under the DSA programme of the University Grants Commission, Rudraiah has contributed a lot to the development of teaching and research activities by holding seminars, short-term courses and conferences.

Rudraiah has won several honours and distinctions. He is an elected fellow of all the three science academies in the country and of the Institute of Mathematics and Its Applications, Britain. He is the recipient of the award of the Federation of Indian Chamber of Commerce and Industry, and he was selected as a National Lecturer by the University Grants Commission. He was elected a Council Member, Vice-President and then President of the Indian Society of Theoretical and Applied Mechanics. As a visiting professor/scientist, he has carried out research work at the Technical University of Munich, University of Manitoba, University of Tokyo, Kyushu Institute of Technology, Tohoku University and the University of Windsor. He has been invited to several international conferences in Canada, Poland, West Germany and China. He is a member of the editorial board of several scientific journals. For more than a decade he was a consultant for theoretical research at the NGEF, Bangalore.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

C S Seshadri

My contributions could be classified under the following heads: (1) Classification of vector bundles, (2) Quotient spaces, and (3) Geometry of G/P.

(1) Classification of Vector Bundles

(a) *Affine case*: Serre posed the problem whether an algebraic vector bundle over the affine n-space is trivial. The case $n = 1$ is well-known and I gave an affirmative anawer[1] for $n = 2$. Several years later, this problem was answered in the affirmative by Murthy and Towber ($n = 3$) and soon after by Quillen and Suslin (for any n). I also classified vector bundles on the product of an affine curve and an affine line[2].

(b) *Picard variety*: I gave a construction[3] of the Picard variety (i.e. the moduli space of line bundles algebraically equivalent to zero) on *any* complete variety X. The earlier constructions of Chevalley, Chow, Matsusaka, Rosenlicht and Weil were only for the following cases: (i) X, a normal complete variety, and (ii) X, a complete curve (reduced and irreducible). Later, different proofs and more general constructions were given by Artin, Grethendieck and Murre.

(c) *Moduli of vector bundles over smooth projective curves*: Let X be a compact Riemann surface (of genus $g \geqslant 2$). Then in collaboration with M S Narasimhan, I proved[4] that *stable* vector bundles on X (in the sense of Mumford) arise from irreducible unitary representations of the fundamental group of X or some Fachsian groups, naturally associated to X. Later, using Mumford's "Geometric Invariant Theory", I gave[5-6] an "algebraic construction" of the "moduli space of semi-stable vector bundles" on X, which would also work when X is a smooth projective curve, defined over any field k. These were further generalized[7] to construct the "moduli space of parabolic semi-stable vector bundles", in order to algebraize the space of unitary representations of a Fuchsian group Γ acting on the upper half-plane H, such that X is the closure of H/Γ. All this work could be considered as achieving the main geometric goals in a paper initiated by Weil.

(d) *Moduli of vector bundles over singular curves*: In collaboration with Oda, I gave canonical compactifications of the Picard schemes of projective curves with only ordinary double points as singularities and a refined study of these compactifications[8]. Later, I showed[9] that the moduli space of vector bundles could be constructed for any singular curve and that they have good properties, if the curve has only ordinary double points as singularities.

(2) Quotient Spaces

I gave some general theorems for

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quotient spaces under the action of an algebraic group G and, in particular, when G is an abelian variety[10,11]

Mumford stated an important conjecture with the purpose of constructing quotient spaces under the action of a reductive algebraic group G, for applications to moduli problems. I proved this conjecture[6] when G = GL(2). Some partial success was also achieved[12] for any reductive group G. This conjecture was later proved in full generality by Haboush.

(3) Geometry of *G/P*

In collaboration with V Lakshmibai and C Musili, I proved[13] the vanishing theorem for higher cohomology groups for dominant line bundles on flag varieties associated to a classical group G. Later, Kempf proved the required vanishing theorems for any semi-simple algebraic group G.

Hodge gave a canonical basis (by "Standard monomials") for the homogeneous coordinate rings of Grassmannians and their Schubert varieties for their canonical Plucker imbedding. In the last few years, I have been interested in generalizing this work of Hodge in the context of flag varieties, associated with my semi-simple algebraic group G and have written a series of papers[14–18], entitled "Geometry of *G/P*", in collaboration with V Lakshmibai and C Musili. A good generalization has been obtained, especially when G is a *classical group*. The basis of "standard monomials" provides a good tool for the study of Schubert varieties, for example, their Cohen-Macaulay properties and location of their singular loci. The singular locus of a Schubert variety in the flag variety, associated to a classical group G, has been determined[19]. Recently, A Ramanathan has proved many of the consequences we have deduced from standard monomial theory in greater generality by different methods. Lakshmibai is making progress in extending our results to exceptional groups.

I am still working on related questions.

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15. Seshadri C S & Lakshmibai V, Geometry of G/P—II (The work of De Concini and Procesi and the basic conjectures), *Proc Indian Acad Sci*, **87A** (2) (1978) 207-39.

16. Seshadri C S, Lakshmibai V & Musili C, Geometry of G/P—III (standard monomial theory for a wuasi-minuscule P), *Proc Indian Acad Sci*, **87A** (1979) 83-177.

17. Seshadri C S, Lakshmibai V & Musili C, Geometry of G/P—IV (Standard monomial theory for classical types), *Proc Indian Acad Sci*, **88A**, Pt III (4) (September 1979) 279-362.

18. Seshadri C S & Lakshmibai V, Geometry of G/P—V, *J Algebra*, **100** (2) (April 1986).

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S M Shah

Theory of Numbers

I began my research work in theory of numbers, mostly analytic theory of numbers, and published about 10 papers. References to some work are given in the book '*Theory of Numbers*' by G H Hardy and E M Wright (Oxford 1960).

Complex Analysis

I began to work on entire and meromorphic functions, mainly in the growth related functions such as $M(r,f)$, $T(r,f)$ and distribution of zeros related functions $n(r,a)$, $N(r,a)$. My work on these topics is mentioned in Boas RP, *Entire functions* (Academic Press, New York, 1954), Cartwright ML, *Integral functions* (Camb Tract, Cambridge 1962), Hayman WK, *Meromorphic functions* (Oxford University Press 1964), Goldberg AA & Ostrovaski IV, *The distribution of values of meromorphic functions*, [*Izdat "Nauka"* Moscow 1970 (in Russian)]. This subject continued to interest me more than any other branch in mathematics.

Later, I considered growth of entire functions when the coefficients a_n in the power series for $f(z)$ are multiplied by arbitrary numbers ϵ_n, such that $|\epsilon_n| = 1$ or 0 and proved theorems which relate to, by an appropriate choice of ϵ_n, the properties of entire functions defined by gap power series $\Sigma\, a_n z^{\lambda_n}$ The late Prof. A J Macintyre proved that $\Sigma\, \lambda_n$ is convergent; then this function f, assumed to be non-constant, cannot be bounded on any ray $\arg z = \alpha$ $(0 \leqslant \alpha < 2\pi)$ and conjectured that if C is any Jordan curve extending to ∞, then f satisfying the above condition cannot be bounded on C.

(iii) Later, I studied the properties of entire functions of bounded index (b.i.), and bounded value distribution (b.v.d.). Let $n[a,R,1/(f - W)]$ denote the number of zeros of an entire function $f(z) - W$ $(W \epsilon C)$ in the disc $|z - a| < R$ $(a \epsilon C, R > 0)$. An entire function f is said to be of b.v.d. if for every $R > 0$, there exists a fixed integer $P(R) > 0$, such that $n(a,R, 1/(f - W) \leqslant P(R)$, for all $a \epsilon C$ and all w C. f is said to be of *b.i.* if there exists an integer $N \geqslant 0$, such that for all $z \epsilon C$ and for all prositive integers k

$$\underset{0 \leqslant j \leqslant N}{\mathrm{man}} \left\{ \frac{|f^{(j)}(z)|}{j!} \right\} \geqslant \frac{|f^{(k)}(z)|}{k!}$$

The least such integer N is called the index of f. These two concepts are related[4,5] [also, Hayman W K, *Pacif J Math*, **44** (1973), 117-37]. I proved that the functions of *b.i.* are all of exponential type; if N is the index number of f then

$$|f(z)| \leqslant A \exp \; (N + 1)|z|\}$$

and this bound is sharp. I also proved that if f satisfies a differential equation (d.e.) with polynomial coefficients $P_k(z)$, $P_o(z)f^{(k)}(z) + \ldots P_k(z)f(z) = 0$ and if deg (a)

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deg $P_0 \geqslant$ deg P_j for all $0 \leqslant j \leqslant k$, then f is of *b.i.* This theorem was later extended in a joint paper by Fricke, Roy and Shah, and later on, by Roy and Shah, to meromorphic functions and to entire solutions of a d.e. where the condition (a) is not satisfied. In a joint paper with J Gopala Krishna, we defined *B.i.* for a function of several variables and proved a number of properties.

(iv) The functions regular and univalent in the unit disc (D) have been studied by a number of workers since the work of Koebe and Bieberbach. Bieberbach's conjecture that if $f(z) = z + \sum_2^\infty a_n z^n$ is regular and univalent in D and normalized then $|a_n| \leqslant n$ equality if f is Koebe function, has been proved recently. In a series of papers, S Y Trimble and I considered a subclass of functions with all successive derivatives univalent in D and proved that this class of functions (E) must be entire and exponential type $T \leqslant 2\alpha$, where $\alpha = \sup \{|a_2|; f \epsilon E\}$. Lachance obtained a bound on α and Dr Sathaye and I improved on this bound on constant α and gave an example to show that the value of this constant α is sharp for a subclass of E. Prof Don Buckholtz and I considered a similar problem in two papers and showed also that our values of constants are sharp. Another class of univalent functions with Gelfond-Leontev deviates were studied in a joint paper with Dr O P Juneja.

(v) My current interests are in difference equations and differential equations. Earlier, I published two papers on difference equations. These papers are referred to in the book '*Differential-Difference Equations*' of R Bellman and K L Cooke. In two joint papers with R Roy, we considered meromorphic functions W satisfying a differential equation for bounds on Nevanlinna characteristic $T(r,W)$, and a similar problem. In three joint papers with Prof Joseph Wiener, we published a survey as well as new results on distributional and entire solutions of ordinary differential and functional differential equations and advanced differential equations with piecewise constant argument deviations.

I would like to acknowledge here the guidance and help by the late Dr T Vijayaraghavan and by Dr V Ganapati Iyer.

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3. Shah S M, Rees C S & Stanojevic C V, *Theory and applications of Fourier analysis* (Marcel Dekker, New York) 1981.
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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

T N Shorey

Let α_1 and α_2 be non-zero algebraic numbers. If log α_1 and log α_2 are linearly independent over rationals, then they are linearly independent over algebraic numbers. This was proved by Gel'fond and Schneider, independently, and this solved Hilbert's seventh problem. Let $\alpha_1, \ldots, \alpha_n$ be non-zero algebraic numbers. Baker generalized the theorem of Gel'fond and Schneider by proving that the linear independence of log $\alpha_1, \ldots,$ log α_n over rationals implies the linear independence of log $\alpha_1, \ldots,$ log α_n over algebraic numbers. Improvements and variations of this result are essential in several problems in number theory. This field is known as the theory of linear forms in logarithms. I have worked on the theory of linear forms in logarithms and its applications to Diophantine equations, sequences of integers and recursive sequences.

Selected Publications

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S S Shrikhande

The subject of combinatorics has had its beginning in a number of puzzles which have not lost their charm. Among these are Euler's problem of the 36 officers and the Konigsberg bridge problem and the Reverend T P Kirkman's problem of 15 school girls. Combinatorics can be regarded as a part of the general theory of configurations on a finite set satisfying some nontrivial conditions. This subject has seen an exponential growth in the last 40 years, as is vouchsafed by more than a dozen research journals in this field with international standing.

Recent developments in the subject were initiated in India in the later half of the thirties by R C Bose at the Indian Statistical Institute, Calcutta. Shrikhande was very fortunate in coming in contact with him at Calcutta and then later at the University of North Carolina at Chapel Hill, where he completed his PhD in Mathematical Statistics in 1950 under his guidance. This started life-long cooperation between them during which period they made very significant contributions to the subject. Shrikhande has to his credit more than 60 research papers as many as one fifth of which were jointly written with Prof. Bose.

Shrikhande's contributions have been in the areas of construction, nonexistence and the number of nonisomorphic solutions of designs as also in the embedding problems of designs and the related graph theory.

Methods for constructing designs can be broadly classified into two categories: direct construction and composition methods. Shrikhande made contributions to both these methods. In particular, the main method used in construction of Latin squares to disprove the celebrated conjecture of Euler made in 1782 about the nonexistence of two mutually orthogonal Latin squares of order $4t + 2$ (which is a generalization of the problem of 36 officers), namely using pairwise balanced designs for composition has been used for many other classes of designs by Hanani, Raychaudhuri, Wilson and others.

In the later half of this century, there were attempts to prove Euler's conjecture. In fact, on the basis of a computer search, it was estimated that the time required to settle the conjecture for the case $t = 2$, i.e. for Latin squares of size 10 may be of the order 2.4×10^9 sec. E T Parker disproved a strong version of Euler's conjecture. The first counter-example to Euler's conjecture was given by Bose and Shrikhande. Improving their result, the complete disproof of the conjecture for $t \geqslant 2$ was given jointly by Bose, Shrikhande and Parker. This piece of research is now regarded a classic and was prominently

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announced in the Sunday edition of New York Times of 26 April 1959. Using the main theorem of this paper and some number-theoretic results, S Chawla, P Erdos and E G Straus were able to show that the number of mutually orthogonal Latin squares of size n tends to infinity as n tends to ∞. Their result was further strengthened by R M Wilson.

The early work of Shrikhande was concerned with the impossibility of certain statistical designs. It was based on the method of Bruck and Ryser, who obtained the first result on the non-existence of finite projective planes. Shrikhande, in several papers extended considerably this method to cover a large class of balanced and (with Raghavrao and Tharthare) partially balanced designs which have some nice structure and are used in statistics related to agricultural experiments.

Let D be an existing $(4t + 3, 2t + 1, t)$ design. In a joint paper with V N Bhat, Shrikhande showed for the first time that the number of nonisomorphic solutions of a design with parameters $2_\alpha(4t + 4) - 1$, $2_\alpha(2t + 2) - 1$, $2_\alpha(t + 1) - 1$ tends to ∞ linearly as n tends to ∞. This result was strengthened by N M Singhi and later by D Jungnickel, who showed that this number tends to ∞ exponentially with α.

Shrikhande has made original contributions to the problem of embedding a given design in another design from which it could possibly have arisen. Some of these problems lead in a natural manner to the problem of characterizing a strongly regular or a strongly regular multigraph by their parameters. His paper on the characterization of a $L_2(n)$ graph led R H Bruck to solve the important problem of embedding a set of $n - 1 - d$ mutually orthogonal Latin squares of size n in a complete set of $n - 1$ such squares. Bruck's results were further generalized by R C Bose for the case of partial geometries.

Later, Shrikhande, in a joint paper with Bhagwandas, extended some of these techniques to the more general case of orthogonal arrays. These results were further extended by him recently (jointly with N M Singhi). His paper with N M Singhi on the embedding of a quasi-residual design with $\lambda = 3$ led to a joint paper by Bose, Shrikhande and Singhi in which it was shown that a quasi-residual design with $\lambda \geqslant 3$ can always be embedded in a corresponding symmetric design, if the block size is greater than a certain function of λ. This paper has led to a large number of results which essentially use their technique.

Recently, Shrikhande has been more interested in some problems related to symmetric designs. In a joint paper with R C Bose, he extended a well known theorem of Erdos and de Bruijn and constructed a large class of the so-called $G_2(d)$ graphs. In a joint paper with Singhi, he proved the well known λ-design conjecture of Ryser, for all prime numbers λ, which still is the best known result on this topic.

With the departure of R C Bose to USA in the later half of the forties, there was a lull in the research activities in India in this field. On his return to India in 1960, Shrikhande tried to make up for it to some extent by creating an active group in the University of Bombay, where he headed the Centre for Advanced Study in Mathematics till 1978. He has also given active support to the enthusiastic band of workers in the Indian Statistical Institute, Calcutta with which he has had a long association for the last 45 years. He is now devoted to developing this area in the Mehta Research Institute of Mathematics and Mathematical Physics.

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M Raziuddin Siddiqui

Up to the first quarter of this century, not many physical phenomena were known which gave rise to boundary value problems in non-linear differential and integral equations. But the situation started changing rapidly since the second quarter of the century, when I began my research work in Germany in the 1930's after completing the mathematics Tripos at Cambridge.

Modern explanations for various physical phenomena were found to be yielding more and more non-linear equations. I had gone to the Leipzig University to meet and work with Prof. W Heisenberg, who had discovered quantum mechanics just about that time, and I was also interested in working with him. But since he was away from Leipzig on a lecture tour to Japan and other countries, I attended some seminars at the Mathematics and Physics Institute of the University, and I was struck by the fact that the derivation of non-linear equations for explaining physical phenomena necessitated the development of methods for proving the existence and uniqueness of the solutions of non-linear partial differential equations. I had made a thorough study of the linear equations at Cambridge. So, at Leipzig, I took up a systematic study of non-linear equations of all types—parabolic, elliptic and hyperbolic.

Up to that time, the method generally adopted to deal with partial differential equations, whether linear or non-linear, was that of Green's function, well-known in the potential theory. A similar method was later developed for the parabolic equations also.

However, in physical theories as well as in mathematical analysis, the solution of a boundary value problem in the form of a Fourier series or a series of eigenvalues is specially significant and valuable. In fact, since the classical work of Fourier himself, the linear problems had often been solved by the Fourier method. An occasional paper was published on the solution of non-linear hyperbolic equations by the application of the Fourier method, but I took up the problem systematically, and in a series of papers extending over a number of years developed the Fourier method for dealing with non-linear equations of different types, subject to various kinds of boundary conditions and boundary domains. I dealt not only with single equations but also with systems of equations.

Lucknow University invited me in 1938 to give a series of lectures on my research work on non-linear partial differential equations, and wanted me to write a monograph on the subject, so that it could be published by the university. I utilized

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this opportunity to develop generalizations of the results published previously in national and international journals. A selected list of the papers is appended to this account.

In connection with these generalizations, I had to work on the series of Sturm-Liouville eigen functions as extensions of the ordinary Fourier series of trigonometric functions.

I had also to develop a theory of non-linear integral equations, not only single equations but infinite systems of non-linear integral equations. I had also to deal with non-linear equations of the second order as also of higher even orders. The work was extended to elliptic parabolic equations, and was further generalized to deal with not only the first kind of boundary value problem, but also with the mixed boundary problem. It was generalized still further to deal not only with the rectangular domains but also with non-rectangular domains. Subsequently, S Minakshi Sundaram worked under my guidance on some problems of non-linear equations which yielded integro-differential equations.

Having rounded up the theory of non-linear differential and integral equations, I turned to a study of the hyper-complex spaces, and their applications in relativistic quantum mechanics. Starting with the matricial representation of quarternions, and working on the field of operators in quaternions, I went on to show that if the elements of the matrices in Heisenberg's quantum mechanics are taken to be quaternions instead of ordinary complex numbers, it would be natural to deduce Dirac's relativistic wave-equation of the electron while retaining the four-dimensional character of the variable throughout.

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M P Singh

Singh got his MSc (Mathematics) from Lucknow University in 1953 and PhD (Applied Mathematics) from Maryland University, USA, in 1962. He worked as a Lecturer in Civil Engineering School, Lucknow (1953-56) and Birla Institute of Technology, Ranchi (1956-59); Research Associate at Cornell University (1962-63); and NASA, USA (1963-64); Assistant Professor, IIT, Delhi (1964-68); and Professor, IIT Delhi (1968 todate). He is currently Head, Centre for Advanced Studies in Atmospheric Sciences, IIT, Delhi, cosponsored by the India Meteorological Department, with main thrust on the development of numerical models for the atmospheric and oceanic processes relevant to the tropics. He has been visiting scientist/professor at University of Calgary, Canada (1972 and 1974); Cambridge University, UK (1973); National Institute for Informatics and Automatics, France (1976 and 1978); and University of Reading, UK (1980).

Singh's career started with research in magnetohydrodynamics and singular perturbation techniques. His current areas of interest include physiological fluid dynamics, atmospheric processes, including development of air pollution models and related fields. Recent work with his associate, S Ghosh, on the development of a mathematical model for the dispersion of MIC in Bhopal gas leak has attracted considerable attention of the international scientific community interested in this area. He has supervised several sponsored projects supported by Department of Science and Technology, Defence Research & Development Organisation and India Meteorological Department in relevant areas of his research interest.

At the Centre for Atmospheric Sciences, a variable grid general circulation model has been developed and integrated for 5 days on a computer in New Delhi. A spectral general circulation model has been installed at the computer and integrated for several days. The centre has developed the capability and expertise for a general circulation model which can be useful for medium range weather forecasting. A numerical storm surge model has been developed and installed at India Meteorological Department computer for trial run.

The centre has developed several mathematical models which can be useful for planning and siting of industries and development of residential colonies. Models have been developed which can be useful as emergency response in case an accident takes place at a facility where toxic materials are stored. Singh has been instrumental in initiating at the centre cooperative programmes with some

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leading French, British and US universities and institutions. Singh is also actively involved in consultancy projects sponsored by the industries and defence departments in respect of determining zone of influence due to accidental release of toxic material from industrial installations.

Singh has been giving lectures and seminars in his area of speciality at a number of universities. At the invitation of the Chinese Academy of Sciences and the Polish Academy of Sciences, he visited China and Poland in 1980 and 1978 respectively. He was a member of the Indian delegation to the WMO Conference on Climatology held in Canton (China) in 1980 and was a member of the Indian delegation to the Indo-US meeting on monsoon meteorology, now called STI.

He was invited as a "foreign guest" to speak at the fourth congress of "The Japan Society of Biorheology" in 1982. He attended the Canadian Congress of Theoretical and Applied Mechanics in 1974 and was a member of the Indian delegation to the Asian Regional Seminar on Relevance in Science and Mathematics Education in 1978. He is a member of the National Organizing Committee for the Asian Congress of Fluid Mechanics. He was an invited speaker at the International Workshop on monsoon dynamics organised in Dhaka, under the sponsorship of ICTP, Trieste, Italy, 1982.

Singh has played a pioneering role in the development of multi-disciplinary activities in the country. He organized several workshops and conferences for the improvement of quality of school teachers (1970); university teachers (1970); National Talent Science Scholars (1970); Advanced level workshop in fluid dynamics (1970); National symposium on algebra and topology (1971); National symposium on development of curriculum in applied mathematics for engineering students (1972); Multidisciplinary workshop on physiological fluid dynamics (1975); Indo-French school on numerical weather prediction (1977); IUTAM/IUGG sponsored international symposium on monsoon dynamics (1977); Indo-French school on recent advances in computer oriented techniques in atmospheric sciences, biomechanics and applied systems (1980); National conference on climate variability (1984); International meeting sponsored by CCCO panel on Indian Ocean on oceanic processes (1985); and International symposium on recent advances in the numerical models for the dispersion of atmospheric pollutants (1986).

Singh is a Fellow of the Indian National Science Academy and the National Academy of Sciences, Allahabad. He was President of the Physical Sciences Section of the National Academy of Science, Allahabad in 1974. He was awarded the Parmar Memorial Gold Medal and he delivered the fourth Dr Parmar Memorial Lecture. He was elected Sectional President of the Indian Science Congress Association during the year 1985-86 and is currently a member of the Council of the Indian Mathematical Society. He is also a member of the Executive Council of the Indian Meteorological Society. He was a UGC National Lecturer during the year 1976-77.

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V R Thiruvenkatachar

The main thrust of Thiruvenkatachar's work has been on finding solutions for specific boundary and initial problems in several areas of applied mathematics. These problems are mathematical formulations of certain concrete problems of technological interest. A brief account of some of these studies is given below.

(1) Problems of Elastic Wave Propagation

The problems considered here are concerned with the analysis of the system of waves in an elastic medium (infinite slab/half-space) generated by a source of finite extent at one of the bounding surfaces. Most previous investigations in this field, starting from the classic paper of Lamb [Lamb H, *Phil Trans R Soc*, **203A** (1904) 1-42] deal only with point or line sources. [cf The comprehensive survey given in Ewing, Jardetsky and Press (*Elastic waves in layered media*, McGraw Hill, 1957.] Two types of problems involving finite sources have been studied in the work reported here.

(i) The first problem relates to waves generated by impulsive pressure over a circular area of one face of an infinite slab of finite thickness and is suggested by the phenomenon of "scabbing" of a metal plate by an explosive charge detonated on one of the faces. It was shown by Thiruvenkatachar[1] that the solution can be expressed as an infinite series, the successive terms of which can be identified as waves arising out of successive reflections at the two faces of the initial P- and S-waves. These initial waves are represented by the first term in the series expansion and are the only waves generated when the slab thickness is infinite, as has been discussed in another paper[2]. A preliminary report of this work was presented by Thiruvenkatachar[3]. The study was pursued further in detail by Viswanathan and Biswas [*Indian J pure appl Math*, **1** (1970)].

(ii) The second type of problems studied differ from the above in that they involve not only sources of finite extent but also boundary surfaces of different geometrical species. Very little work had been done on such problems. Lately, such problems have gained importance in the interpretation of seismological data relating to seismic disturbances, both natural and those induced by underground explosions. In a series of papers[4], the system of waves generated in an elastic half-space with a traction-free plane boundary by time-dependent surface tractions over the surface of an embedded spherical cavity was analysed. A notable feature of this work is the iterative method of solution, in which the displacement potentials ϕ and ψ are expressed as infinite series:

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$$\phi = \phi_0 + \phi_1 + \phi_2 \ldots$$

$$\psi = \psi_0 + \psi_1 + \psi_2 \ldots$$

where (a) ϕ_m and ψ_m satisfy the corresponding wave equations

(b) ϕ_0 and ψ_0 satisfy the boundary condition at the cavity surface only

(c) $\phi_{2m} + \phi_{2m+1}$ and $\psi_{2m} + \psi_{2m+1}$ satisfy the boundary condition at the free surface, ($m = 0,1,2,\ldots$)

(d) $\phi_{2m-1} + \phi_{2m}$ and $\psi_{2m-1} + \psi_{2m}$ satisfy the stress-free condition ($m = 1,2.\ldots$) at the cavity surface.

It is shown rigorously that the series for ϕ and ψ are convergent in the region occupied by the medium and represent the solution satisfying all the boundary conditions. In an earlier paper[5], the corresponding problem of the plane face had been solved on the same lines.

(iii) The same iterative method of solution was used in another study[6] to solve the problem of determining the field induced by an oscillating electric dipole above a conducting half-space with an embedded dielectric sphere. This is a generalization of the classic solutions of Sommerfeld and Weyl for the case in which there is no dielectric inclusion. This problem has relevance to certain detection techniques used in geophysical prospecting (detection of underground masses) and other similar contexts.

(iv) Two other problems of seismological interest were studied[7,8]. The first of these analysed the system of waves in a composite elastic half-space consisting of two wedges of supplementary angles welded together, by a line source in one of the wedges. This model is of interest in the study of propagation of seismic waves across oceans and continents.

(v) The other problem treated[8] represents an idealized version of the seismological problem: to determine the waves induced in the earth (treated as a spherical shell with a liquid-filled core) by a point source in the solid shell.

(2) Fluid Flow Problems

These problems relate to compressible fluid flow, conical flows and gravitational instability of a fluid mass.

(i) In one study[9], the hodograph method developed by C C Lin was applied to derive formulae for the force and moment in subsonic two-dimensional flow of a compressible fluid, which are the analogues of Blasius's formulae for the incompressible case.

(ii) The problem of a thin airfoil in compressible shear flow was also studied[10]. The case of steady supersonic flow was considered[10] and expressions for the lift and drag were derived. The solution of the corresponding problem for non-steady motion was derived applying Hadamard's method[10].

(iii) Conditions characterizing conical flows were investigated[11] and the implications of relaxing the usual assumption of constancy of velocity components along rays through the origin were examined.

(iv) The conditions for the gravitational stability of an infinite homogeneous non-viscous medium—a problem which arises in cosmology—was first treated by Jeans, who derived the well-known instability criterion bearing his name. Fermi, Chandrasekhar and other subsequent investigators showed that Jeans's criterion remains unaffected by the presence of rotation and magnetic field, either separately or simultaneously; but the effect of thermal conduction is to replace the adiabatic sound velocity by its isothermal value in the stability criterion. Thiruvenkatachar and Khosla[12] studied the effect of radiative transfer on Jeans's criterion and showed that even in the general case of the presence of a uniform rotation and a uniform magnetic field, the effect is the same as in the case of thermal condition.

(3) Some Problems of Heat Transfer

Some problems relating to heat flow in a finite composite cylinder were studied[13,14]. In one paper[13], the case of combined radial and axial heat flow in a finite composite cylinder consisting of a core and a concentric shell of different materials under homogeneous boundary conditions and uniform initial condition was discussed. As extension of this problem in which the surface temperature is a harmonic function of time was treated later[14]. This problem is of considerable significance in the study of the response of thermocouples and hot wire anemometers to rapid changes of environmental temperatures. The solution of the composite hollow cylinder problem in a very general form was later given by N Y Olcer whose paper contains a review of earlier work also [Olcer NY, *Q appl Math*, **26** (1968)].

Another problem of some practical interest, viz., the flow of heat between a buried pipe or cable and the surface of the ground involves study of temperature distribution in a semi-infinite solid due to prescribed heat supply over the surface of an internal cylindrical cavity. The solution was constructed by the same iteration technique as was used for the elastic wave problem discussed earlier. The question whether the system attains a steady state remains open.

The technique of double Laplace transformations introduced by J C Jaeger was applied for solving several problems in heat conduction[15].

(4) Miscellaneous Studies

Among other miscellaneous problems studied, the following deserve mention: (i) Free oscillations of a non-linear system with two degrees of freedom[16], and (ii) a new derivation of the Kerr metric for the gravitational field of a rotating spherical mass[17].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S K Trehan

The outstanding research contributions of Trehan are discussed below in brief.

(1) The stability of force-free magnetic fields was examined by Trehan for the first time in 1956. His results have been quoted in various sources, including the *Physics Handbook* (Vol. 51, page 718).

(2) The two review articles on 'Plasma Oscillations' written by Trehan have been a source material on the subject and have been reproduced by the American Institute of Physics under the scheme 'Selected Reprints' in the book '*Small amplitude waves in plasma*'.

(3) The lecture notes on 'Plasma Physics' compiled by Trehan have been published by the University of Chicago Press under the 'Midway Reprints' series.

(4) The analytic treatment of the 'Effect of Coulomb Collisions on Contrastreaming Plasmas' published in *Annals of Physics* (Vol. 40, p. 296-320) was a very significant improvement over the results of the Princeton group, which solved the problem numerically on the computer. Our analysis showed for the first time the relative contributions of the various terms in the collisions.

(5) Trehan's work on magnetic polytropes is highly significant in that it gives for the first time a *consistent mathematical theory* of self-gravitating gaseous masses in the presence of a magnetic field, since the pioneering work of Chandrasekhar (1952), Chandrasekhar and Prendergast (1956) and Woltjer (1962).

The observation (mathematical) of Trehan that in astrophysical bodies the toroidal component of the magnetic field will be substantially larger than the poloidal component is now being supported by several other investigators.

(6) Trehan showed for the first time that a toroidal magnetic field does not affect the point of bifurcation where the Jacobi ellipsoids branch off from the sequence of Maclaurin spheroids. However, the point of onset of dynamical stability is shifted to higher values of eccentricity compared to the value which prevails in the absence of a magnetic field.

(7) Trehan is currently engaged in non-linear stability studies in magnetohydrodynamics with the possibility of applications in astrophysical situations. RW Lardner and Trehan have jointly given for the first time a consistent account of the modulational stability of bounded systems, taking into account the boundary conditions consistently.

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Sectional Committee—II : Physics

(Astronomy and Astrophysics, Physics of Materials, Space Physics, Subatomic, Atomic and Molecular Physics, and Theoretical Physics)

G S Agarwal

Agarwal has specialized in the field of quantum optics and has contributed extensively to its development. He has also worked on problems in other areas of physics, such as surface optics and non-equilibrium phase transitions. In what follows he has chosen to describe his contributions to the theory of optical resonance and cooperative phenomena.

Optical Resonance and Cooperative Phenomena in Intense Laser Fields

Agarwal formulated a quantum statistical theory of super-radiance and derived a master equation for dynamical behaviour, which later became the basis for the discovery of the cooperative resonance fluorescence[1]. In his research monograph[2] on quantum optics, a systematic quantum electrodynamic theory of resonance fluorescence in intense fields was presented for the first time. The approach outlined in this monograph became the basis for many theoretical studies in quantum optics. Haroche and coworkers have carried out many experiments on cooperative effects in Rydberg atoms. Recently, Agarwal obtained exact results[3] on the absorption spectrum of a cooperative system in a cavity and has proposed another experiment which will enable one to see the cooperative effects in a clean way.

Cooperative effects have also been shown to be of great importance in understanding multiphoton ionization in atomic vapours at high pressures[4]. A general theory for the generation of VUV radiation has been formulated. Work is being done in several laboratories to achieve laser action in the far VUV using multiphoton excitation of the high lying states.

Optical bistability was discovered in 1976 in atomic vapours under intense pumping conditions by Gibbs *et al.* Agarwal, in collaboration with Drexel group, formulated the quantum theory[5] of this remarkable effect and made detailed predictions of the fluctuations in such systems. More recently, many universal features[6], such as exponents, of such multistable systems, were found in collaboration with S R Shenoy. Models for optical bistability in solid state systems[7] involving elementary excitations have been proposed. Such models can also account for bistability in multiphoton situations. Ikeda *et al.* showed how strongly driven optical systems can exhibit turbulent behaviour. Along with Singh[8], Agarwal gave a theory for the turbulent behaviour of the atomic systems under strong coherent two-photon pumping conditions. The work on optical turbulence has been responsible for renewal of interest in instabilities in various types of laser systems, nonlinear optical systems, etc.

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Agarwal was the first to present a model of laser fluctuations for which optical resonance equations were exactly soluble[9]. The techniques described in these papers were subsequently used by a host of workers in quantum optics to look at other dynamical systems. The formulations presented in these papers have been applied to explain the results of the recent experiments of Devoe and Brewer on free induction decay. The general theory[10] of relaxation dynamics in intense laser fields has been proposed by Agarwal and the applicability of optical Bloch equations has been discussed. The results reported in these papers can well form the theoretical basis for nonlinear spectroscopy using incoherent sources.

One of the major spectroscopic problems was to obtain resolution beyond natural linewidth. Agarwal, along with his student R Saxena, formulated a technique[11] that enables one to resolve lines within natural linewidth. The four-wave mixing signals produced by homogeneously broadened systems are also shown to have subnatural linewidths under certain conditions. Multiphoton processes[12] in the field of two strong pumps also exhibit subradiative structures. Other groups are hoping to use transient methods such as the one involving CARS to produce narrower lines.

Agarwal, in collaboration with S S Jha, showed[13] how the usual Raman spectra undergo dramatic changes in resonant situations if the fields used to excite the system are very strong. He has also been responsible (with his student P Anantha Lakshmi) for the theory[14] of the recently discovered Optical Hanle effect. A systematic study of the multiphoton processes in the field of two saturating pumps[12] enables one to investigate the effects of saturation on a large number of nonlinear optical processes. Using this approach, important results in the area of phase conjugation in resonant systems (modulation spectroscopy) have been obtained. Existence of pressure induced extra-resonances in phase conjugate signals has been shown. Recent experiments necessitate the form of *n*th order susceptibility for an arbitrarily relaxing system, so that the effects of collisions in nonlinear spectroscopic problems can be studied systematically. Multiphoton processes in bound-free transitions have been studied. A general theory for the laser induced autoionization has been suggested[15]. It has been shown[15] how the efficiency of the nonlinear mixing processes using autoionizing states can be enhanced by properly choosing the laser intensity. The formulation proposed in the monograph[2] on 'Quantum Optics' has been shown to be useful in obtaining line shapes which systematically account for the effects of radiative recombination and dielectronic recombination.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

F C Auluck

There is a deep connection between problems in statistical mechanics and problems in the partition theory of numbers. The number-theoretic methods are elegant and also more powerful. If $p_k(n)$ denotes the number of partitions of an integer n into k summands, the value of k for which $p_k(n)$ is maximum is evaluated. Bipartite partitions are defined and evaluated. The properties of partitions are extended to non-integral summands.

Quantum mechanics of a bounded linear simple harmonic oscillator is discussed in a series of papers, and the energy levels as a function of the dimension of boundary have been obtained. The results are used to calculate the effect of high pressures in astrophysical situations. The theory of pressure ionization leads to a mass-radius relation for white dwarf stars and planets. The electrostatic fields are of great importance in the case of planets and the gravitational field in the case of white dwarf stars. Thus, any theory on the evolution of stars must take into account the electrostatic fields.

The effect of radiation field on the Lamb shift is studied in a series of papers. This radiation Lamb shift depends on the temperature of the assembly or intensity of the radiation field. This shift is of astrophysical significance. The effect has been observed in the laboratory using powerful ruby laser pulses.

The electronic properties of complex atoms can be studied by incorporating in the Thomas-Fermi Theory such terms as correlation energy and quantum corrections. Single-particle energy levels of neutral atoms have been calculated. A new angular momentum assignment is proposed and relativistic mass-velocity correction incorporated. The effect of high pressures on atomic structures and the equation of state of dense matter have been investigated. The possibility of superconductivity in dense matter is studied.

The problem of random fragmentation of a given volume into fragments is important in astrophysical situations. Auluck's group has obtained asymptotic expressions for a number of elements with volume greater than or equal to an assigned value V for all values of V. The results have been applied to the problem of mass function for stars and galaxies. The theory agrees very well with the observed data.

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D Basu

(1) The theories of pianoforte string were studied by Helmholtz and others on the basis of a hammer striking the string at a point. Lord Rayleigh pointed out that 'some allowance must be made for the finite breadth of the hammer striking the string; following his suggestion, the effect of finite breadth of the hammer striking the string was studied and it was found that the finite breadth has an important effect on the duration of contact as well as on the maximum displacement[1]. The duration of contact has been found experimentally for different breadths of contact ranging from 1.0 to 3.0 cm and compared with those for point contact[2].

(2) Taking a simple exponential potential, the parameters of which have been calculated from the known binding energy of deuteron, neutron-proton scattering has been evaluated by the perturbation method and found to be isotropic with angle in the first approximation. But it depends on the angle in the second approximation[3].

(3) Using the perturbation method, the scattering of proton by proton was calculated taking into account both the Coulomb potential and the short range nuclear interaction at energies near about 1 MeV: the differential cross-section data were compared with the experimental values at 900 keV, 800 keV and 700 keV and found to be in good agreement with them; the differential cross section increases from 20° to 45°[4].

(4) An examination of the calculation of the Klien-Nishina formula as per the original Dirac theory and the hole theory was made[5,6].

(5) Calculation of the capture of electrons by positive ions passing through gases shows that contrary to the opinion of Brinkman and Kramers, the probability of capture of an electron by the α-particle in the $2p$-orbit from H-atom becomes much larger than that for the capture in the 1s-orbit when the velocity falls below $2(2\pi e^2)/h$. For small velocity, the ratio of $2p$ capture to 1s goes on increasing[7].

(6) Exact calculations were made relativistically for the differential and total cross sections of neutron-proton scattering in Born approximation using vector and pseudoscalar fields of various types and mixtures. The effect on these was found when terms were introduced in the Hamiltonian to eliminate singular S-type terms in the 'static' interaction potential; even then the cross section increased with increase in neutron momentum[8].

(7) Numerical values were calculated for neutron-proton scattering cross sections radiation damping at energies from 100 to 2000 MeV, at $E \sim 500$ MeV; the theoretical value was $15/E$ barns[9]

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Different aspects of neutron-proton scattering were studied with reference to meson production in such collisions[10-12,15]

(8) Electron capture processes in ion-atom collisions play important roles in astrophysics, atmospheric physics and plasma physics. The occurrence of ionized helium lines in solar corona is explained by the process of electron capture by fast alpha-particles produced in nuclear reaction. The auroral lines originate from photons streaming out of sun and capturing electrons in excited states in the earth's atmosphere near the 'poles'. The energy transfer through charge-exchange between hydrogen ion and their gaseous matter as impurity plays an important role in plasma physics. With this in view, different charge exchange processes were studied[16-26]

(9) The study of charged particle production (multiplicity) in proton-proton collisions at high energies gives information about the asymptotic behaviour of the strong interactions involving hadrons. In pursuance of this, the data from the National Accelerator Laboratory, Batavia and CERN and also on cosmic rays have been examined critically[27-35].

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J C Bhattacharyya

The eternal questions about the sky and the universe have fired our imagination ever since the birth of human consciousness. Over the ages we have been able to unfold some of the enigmas of nature. At all stages, the depth of our understanding depended on the quality of probes used in investigations. In our times, there have been tremendous advances in the methods of scientific investigations; some applications have brought about a clearer view of the processes in our nearby corner of the universe. Bhattacharyya's researches have been concerned mainly with this aspect.

Earth's ionosphere, which acts as a mirror in the sky for radio waves, has been known to be formed due to the interaction of atmospheric gases with solar ionizing radiation. New methods of estimating the ionization profiles were invented and employed in finding the location of these sources on the solar surface[1], and the spectral composition of their radiations[2].

High dispersion spectrographs started functioning at Kodaikanal in the early sixties. New photoelectric methods of polarization analysis along the profiles of Fraunhofer lines opened up possibilities of investigation of weak magnetic fields on the sun. Such an instrument was designed and constructed[3]; it was found that this was ideally suited for studying the characteristics of short period oscillations on the solar surface. A comprehensive study at Kodaikanal provided detailed information on the nature of these oscillations[4].

Development of electronics and new photoelectric detectors made several new types of observations of the universe possible. One of them is recording of transient events, which convey hitherto unobtainable information in astronomy. A new series of instruments were developed and employed in recording such events. Some of these observations unfolded the stratified atmosphere of Jupiter[5], a trace of atmosphere on Jupiter-satellite Ganymede[6], and a ring structure around the planet Uranus[7,8]. The group of experimental scientists created thereby continue to be very active, and their efforts have resulted in another discovery of a new set of faint rings around Saturn in 1984[9].

Application of new techniques in scientific instrumentation continues to dominate Bhattacharyya's interest[10]. In the recently completed 2.34M telescope, several new ideas in the control and data acquisition system have been incorporated. Development of new types of CCD cameras and image processing systems which is expected to bring about a revolution in observational astronomy is

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one of the main aims of Bhattacharyya's current research work.

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S N Biswas

I have been working in various branches of theoretical physics for a long period. I have contributed in many fields, such as quantum theory, lasers, statistical mechanics, mathematical ecology, etc. but always kept my main interest in high energy particle physics. With the changing scenes in theoretical particle physics, I have always engaged myself in its rapid development. I started my early work in the study of relativistic quantum mechanics of bound system in the framework of covariant field theory. My further contribution in this field is in obtaining a dynamical symmetry group obeyed by covariant bound state equation known as Bethe-Salpeter equation. In quantum electrodynamics, I have obtained non-perturbative results with vanishing electron mass identical to those obtained otherwise by Baker, Johnson and Willey. With the advent of unitary internal symmetry structure of particle physics, I considered the fundamental problem of the mass difference of short- and long-lived components of Kaon and Cp-violation phenomenon in neutral Kaon complex. Development of particle physics through group theory and field theory led to the establishment of algebra of currents and partial conservation of axial currents. Along with my students and colleagues, I have made many contributions in this field. A number of works have been referred to in standard textbooks. During the same time, high energy particle physics witnessed spectacular developments with Heisenberg's S-matrix theory incorporating unitarity, analiticity and Regge theory. I made many contributions along with my students and colleagues. For quite some time I have been working on quantum mechanical eigen value problem. Along with some of my research students and colleagues, I developed non-perturbative method to deal with these problems, in particular, the well known anharmonic oscillator. I developed some of these and other related works in non-polynomial lagrangian theory in my Dalhousie Summer School in Theoretical Physics organized by TIFR, Bombay in 1973. I have also looked into some fundamental problems in scattering theory. For the last few years, along with Prof. V Singh of TIFR, I have developed analytical theory of continued fraction to study eigen value problems in quantum mechanics in a series of papers. Following these works of ours, there has been a spurt in activity in this field and a large number of workers in India and abroad are working on it. With the gauge theory of field, high energy physics has now entered a new era. I have been presently working in this field, with special interest in the field of astrophysical implications of gauge symmetry. I have also worked on statistical mechanics of quark gas for possible phase transition in nuclear to quark matter, assuming

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parastatistics for quarks. Of late, I have worked on the quark confinement and mixing problem in the context of QCD and also on the possible existence of quark star.

The areas of my current interest are supersymmetry and string theory for high energy particle physics.

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Sukumar Biswas

The origin and acceleration of cosmic rays are some of the major unsolved problems in high energy astrophysics. For over past 35 years, Biswas had been engaged in studies on their diverse properties in the area of nuclear physics, high energy physics, elementary particles, galactic cosmic rays, solar cosmic rays, high energy astrophysics and space physics. Many of these studies were carried out using detector systems flown in balloons, rockets, and, more recently, in satellite and spacelab; theoretical studies were made on the results obtained. These provided us with newer clues to their origin and acceleration processes. These investigations were carried out by Biswas in five laboratories in Australia, India and USA.

Biswas started his research career in 1947 in nuclear physics under the guidance of Prof. M N Saha in the newly started Institute of Nuclear Physics of Calcutta University. The work on the experimental determination of fission cross-section of ^{235}U for thermal neutrons was a part of his doctoral thesis. This work[1] was one of the earliest neutron physics works in India and was quoted among the world data of fission cross-sections as the Indian data at the Atom for Peace Conference in Geneva in 1955. This work was included in the Golden Book of Neutrons published by BARC in 1983 as one of the milestone papers among 160 papers on neutron physics published in last 50 years. This work was done when Biswas was 25.

Biswas began cosmic ray studies with newly developed nuclear emulsions flown in a balloon in 1950 at the University of Melbourne, Australia, soon after the discovery of heavy nuclei of cosmic rays in 1949. Highly rewarding studies were made on the detailed measurements of proton-proton collision in emulsions in balloons at 1000 GeV leading to multiple meson production; the degree in elasticity was measured as 0.1 at 1000 GeV[2]. After completing Ph.D. at Melbourne, Biswas joined TIFR in 1952 in the newly formed nuclear emulsion group for studies on cosmic rays with balloons, which was led by B Peters, discoverer of heavy nuclei in cosmic rays with nuclear emulsions. The following several years witnessed prolific activities and Biswas discovered a new method, called 'Constant Sagitta Scattering' for determining accurately the masses of heavy unstable particles in nuclear emulsions. Applying this method, Biswas determined for the first time the mass of k^+ and k^- mesons as 976 me[3]. This method has been a standard method followed in laboratories of the world and is a textbook item. In 1955, another discovery was made by Biswas, which is

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known as spurious scattering in nuclear emulsion; this is a landmark in emulsion technique[4] and is included in textbooks. Several important studies followed[5].

From 1959, Biswas took up investigations in the newly discovered area of solar flare produced energetic particles using detectors in balloons at the University of Minnesota, USA, and in rocket flights from Canadian Arctic Station of NASA Goddard Space Flight Centre of USA. These studies gave pioneering results on solar protons and helium nuclei[6] in balloon flights; in a series of six rocket flights first detailed measurements were made on the composition of solar cosmic-ray heavy nuclei of He, C, N, O, Ne and some heavier nuclei[7,8]. These were found to represent an unbiased sample of matter of solar atmosphere[9]. Thus, from direct observations, the abundances of helium and neon in the Sun were determined for the first time and those of C, N, O in the Sun were determined more accurately than by other methods. This work[7–9] was included in a book '*On the Origin of Cosmic Rays*' by National Science Foundation in 1972 as one of the 60 milestone papers since the discovery of cosmic rays sixty years ago and in textbooks[8].

Since 1964 in TIFR, attention has been given to galactic cosmic ray heavy nuclei and the abundances of helium isotopes in cosmic rays. This yielded one of the early reliable measurements of ^{3}He abundances. Studies were made for the first time on the energy dependent pathlength in space from ^{3}He to ^{4}He ratios[10] and from Li, Be, B abundances[11]. Residual solar modulation parameter was determined from ^{3}He data for the first time and important theoretical calculations on cosmic ray propagation were made[12].

In 1973-74, a detector module of Lexan was exposed in the exterior of Skylab spacecraft of NASA for 74 days with only 24 mg of shielding. On examining the detectors, Biswas and colleagues discovered a new type of low energy cosmic rays at 435 km altitude in near earth space with unusual composition[13]. The Skylab results[14] showed for the first time the strikingly new property that these anomalous cosmic rays are probably in partly ionized state in contrast to fully stripped nuclei in high energy cosmic rays. We concluded that these must be originating from sources distinctly different from those of high energy cosmic rays. Some possible models, such as stellar wind, have been suggested by us.

To probe deeper into this matter, a sophisticated experiment was proposed by Biswas and this was accepted by NASA as the only Indian experiment in the Space Shuttle-Spacelab Mission of NASA and one of the two selected from Asia. This instrument 'Anuradha' (IONS) has novel features and has been designed, fabricated and tested by Indian scientists and engineers of TIFR-PRL-ISRO; it was installed in Spacelab in 1984. This instrument, which is operated and controlled by Spacelab computer, is designed to measure for the first time the ionization states of low energy galactic cosmic ray heavy nuclei and hence to obtain clues to their origin[15]. The experiment had a highly successful flight and operations at 352 km orbit in Spacelab-3 aboard the Shuttle Challenger from 29 April to 6 May 1985. The thurst of the team of scientists of TIFR-PRL in the next few years will be to identify partly ionized ions of cosmic rays and also to understand the properties of heavy ions in the inner magnetosphere. A reflight of IONS instrument in Spacelab in 1989 for solar flare heavy ion studies will be attempted.

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A Bose

When nearing the conclusion of a more than average span of active research career, one is required to look in retrospect, provide a summary perspective of one's little contributions to the existing store of scientific knowledge and to the arts and comforts of life of the people, one is quite at a loss to decide what to reject and what to retain and present. This indecision, in my case, is due to the following main factors: firstly, during the 53 years of my activity as a scientist dedicated to research work, the particular branch of science under consideration has grown from practically a pioneering start in 1932 to a vast interdisciplinary structure in 1985, to which my own specialized contribution has given a substantial integrated build up. Secondly, in this long period, much of the work has become a matter of history, providing the basic material for the said structure, but sometimes with the danger of becoming outmoded by new discoveries. The third factor is personal modesty, which is likely to restrict one from giving a true assessment of the value of the work.

My research career started in 1932 at the Dhaka University as the thesis part of my Master's degree examination, covering the change in diamagnetic susceptibility of a large number of organic substances from crystal to liquid state, too small to appreciably affect the molecular orbitals of the compounds. In the following two years as a Research Scholar at the Indian Association for the Cultivation of Science (IACS), I found that the $^6S_{5/2}$-state of a large number of paramagnetic Mn^{2+} salts was little affected by aqueous solution, whereas in iso-electronic Fe^{3+} ion aqueous solutions, hydrolysis causing ferro/antiferromagnetic colloid formations, induced strong departure from S-state behaviour, which was restored to some degree by increasing acid concentrtion of the solution, retarding hydrolysis.

During this time, enormous data on dia- and paramagnetic anisotropic susceptibilities of crystalline compounds at ambient temperatures had been gathered by my colleagues, late Dr. S L Banerjee and late Prof. A Mookherjee, all of us working as scholars under late Prof. K S Krishnan. Dr Banerjee's work elucidated the crystal structural correlation of electron distribution in the carbon ring compounds and ultimately led to pioneering studies on semiconductor behaviour in crystals. Dr Mookherjee's work on a large number of paramagnetic crystals of iron and rare earth group of salts at room temperature explained and supported some of the basic facts of the crystalline field theory.

However, these works had entered a blind alley for want of extensive study of magnetothermal behaviours of the

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crystals, especially down to very low temperature, which alone could give a full explanation for these behaviours. I posed the problem to Prof. Krishnan, who immediately gave me a green signal and a free hand for the development of low temperture technology and facilities at IACS, Calcutta, then unknown in India and at the time available only in a few specialized laboratories of the world. So I self-taught myself into a cryogenist, made high precision automatic cryostats to liquid air temperature, all-metal cryogen containers, cryogen transfer lines, calibrated cryothermometers, extremely sensitive magnetic anisotropy and susceptibility balances, magnetic field and gradient meters and so on.

Entirely new indigenous knowhow, expertise and technology were developed out of scratch in the face of insignificant monetary and academic help. The source of liquid air and liquid oxygen (no LN_2 was available in those days) was Indian Oxygen Ltd, established in Calcutta in 1935 and a small air liquefier of our own, BOC8, giving 1 litre/hr and run continuously day and night in shift by me and my colleague, late Dr A Mookherjee. Any quantity of solid CO_2 for calibration work was available from the newly set up Magnolia Icecream Factory at Calcutta.

Soon my extensive investigations, as also the works of my two colleagues, Dr A Mookherjee and Dr B C Guha, brought convincing confirmation of late Prof. Van Vleck's theory of crystalline electric fields, such as the near Curie law behaviour and large deviations from Curie and Curie-Weiss laws of a large number of crystalline salts of Cu^{2+}, Ni^{2+} and Fe^{2+}, calculation of spin-orbit coupling in these salts from magnetic data, calculation of crystalline fields, the orbital and spin levels of the salts in crystalline fields, inversion of electric field levels in reciprocally related electronic states of the salts of Cu^{2+} and Fe^{2+} and Co^{2+} and so on (Ref. 1 and later papers).

By this time, cryogenics as an applied field of immense importance had gone to my head. I had drunk deep into the fountain of cryogenic knowledge. At this time (1935), I had an occasion to visit the Calcutta city water supply complex at Tallah, which had just then installed 4 multistage steam turbine driven turbo-waterpumps to supplement or largely replace its two old reciprocating pumps, which fired my imagination deeply by the huge difference in all round efficiency of the turbine systems. I was not aware of the single stage turbine expansion refrigerator just then developed by Linde (1934), but studied the possibility of a hitherto not contemplated multistage turbine for air liquefaction at low pressure, of large pressure drop and high capacity and completed its design, which if constructed would revolutionize the entire liquid air industry. Unfortunately, I could get no financial help from the British governmental authorities of the time and was discouraged and advised by my professor to complete instead DSc thesis, which I did "off my cuff" by 1937. The hard work and disappointment in my cherished objective now made me the victim of a killer disease, from which I suffered for a year and returned practically from the portals of death. After 1938, I had to take up for my living such positions as a Professor of Physics at Shillong, research assistant at Allahabad University, professor at J. I. College, lecturer at Dhaka University and finally returned to IACS in 1947 just after Independence and partition of Bengal, as research officer. I could then resume my research career after a total break of almost 10 years; and making up the leeway was no joke. In the meantime (1940) late Prof. Kapitza had constructed a nice single stage turbine expansion liquefier leaving the ground hollow under my feet. I did not lose heart and again tried to develop the multistage turbo-liquefier with financial help from the newly established CSIR, but strangely enough the CSIR experts could not see the brilliant future of the machine and refused the project as infeasible, whereas in recent times turbine liquefiers have captured the field of large scale cryogenics all over the world; such is the mockery of fate. As a mere consolation I published my preliminary paper on turbine liquefier in 1948[2].

Now, indeed, I was heart and soul diverted to low temperature and solid state physics and launched upon a project of crystal magnetism, extensive and deep. From a wide survey and accurate analysis of paramagnetic properties of crystals of our own and of all the worldwide low temperature laboratories that had sprung up by then, I became convinced that the so-called ligand fields in crystals arising from the quantum and static electric interactions of the immediately surrounding neighbours of a magnetic ion could not explain even the approximate behaviours of the compounds[3–5]. It was essential to take into consideration three intrinsic molecular and long range crystalline orbital interactions, namely, John Teller effect and intramolecular and intermolecular orbital overlap to explain the considerable deviations from the crystalline ligand field theories developed so far by theoreticians. This fact was reported at the first National Conference on Magnetism at IACS (1954) organized by me and also at the first International Conference on Magnetism at Moscow in 1956[7].

Then I was invited to the newly founded National Physical Laboratory by Prof. D Shoenberg, UNESCO Professor and Prof. K S Krishnan, Director (1955) to help in the setting up of the Cryogenic Laboratory, and worked and published a paper on paramagnetic saturation and shape effect at liquid helium temperatures and very high magnetic fields[8]. I was offered the Assistant Directorship of the NPL Cryogenics Division then set up, but could not find it in my heart to desert my second alma-mater, IACS. Perhaps I made a mistake in not taking this opportunity of developing my applied cryogenic bias, which only came again in the last 10 years of my life, as mentioned hereafter. For extending the magnetic measurements to liquid hydrogen temperature I designed and fabricated a mini-hydrogen liquefier-cum-cryostat[9]. These several happenings started altering the balance in my favour. It was by this time clear to me that paramagnetism in crystals as dependent both on molecular and crystalline structure and short and long range orbital overlaps was only one facet of the crystalline state energy spectrum. To get an overall energy picture of the crystals, we must integrate in a common frame the structural data, the magnetic spin level data, the ligand field and configurational level spectroscopic data (microwave, infrared and optical spectral data). Thus, for the first time in this field, I undertook to develop my department (Magnetism Department, 1956) to include facilities for X-ray crystal structure, electron and nuclear resonance, infrared and optical spectroscopy in addition to magnetic properties down to liquid H_2 temperatures. For this purpose, an Andreas Hofer H_2 liquefier was operated, LN_2 supply being all this while available from IOL, Calcutta. Just prior to retirement I also obtained a second hand Collins He liquefier from Rutger University. Prof. C J Gorter, Prof. L F Bates and Prof. D Shoenberg all of whom I met at Moscow Conference (1956) considered this as an ambitious project. I am happy to note in advance that this ambition was well fulfilled and I was able to build up an integrated team when I retired 20 years later.

At the same time I had to develop a complex exact analytical theory for all the magnetic ions of iron group of ions in crystalline fields. Side by side we obtained new experimental data for an extensive number of crystals of iron group, Ti^{3+}, V^{3+}, V^{2+}, Cr^{3+}, Cr^{2+}, Mn^{3+}, Fe^{2+}, Co^{2+}, Co^{3+}, Ni^{3+}, Cu^{2+}, in different ligand configurations, square, tetrahedral, octahedral, trihedral, do-decahedral etc., and fitted these with our own theory. The result was a series of papers of high standard in journals such as *Proc R Soc, Phys Rev, Solid State Phys, Proc phys Soc, Physica*, etc[10-22] and a large number of other equally interesting papers in *Indian J Phys*.

In the course of these investigations, a very interesting and peculiar result was observed in at least 70% of the compounds investigated. The magnetic anisotropy is very sensitive to structural or other kinds of phase transformations. All the available and our own data on crystal and molecular structure, electron resonance, optical spectroscopy and magnetic susceptibility and anisotropy over a wide range of low temperatures could be fitted into a rational framework only by postulating a thermally changing crystalline ligand field, which in many cases is fairly abrupt and more often continuous[10-22]. Small changes in crystalline field parameters, particularly the anisotropy factor, where they occur, are obviously structure sensitive thermal lattice vibration and expansion effects. But quite often these changes are large and continuous and sometimes very abrupt with a thermal hysteresis effect. A satisfactory theory of this anomalous behaviour could at last be developed only after about 20 years of work in 1975 simultaneously by us and by Prof. Elliott of Clarendon Laboratory, Oxford and is contained in the *Proceedings of the International Conference on Solid State Physics* (IACS, Calcutta). We were able to show theoretically that these anomalies were due to a continuous thermal phase transition between coexisting main lattice mode and sublattice and/or superlattice modes, which affected the crystalline orbital overlaps and hence the spins, through spin orbit and spin lattice interactions.

Then came my slightly premature retirement from IACS. I was all the time pining to revert to cryogenics as a progressive force in the country. This opportunity now came, as I was asked by NCIIR to set up the Indian Cryogenics Council in 1975. Now my work has been on the assessment of application of cryogenics in the development of rural and industrial sectors in India[23,24]. I am at present having an R&D project on cryothermometers, cryogen containers, surgical cryoprobes, cryo-food preservation, programmed freezethaw apparatus for blood, tissue, bones, organs and all other biological specimens, rural biogas, frozen food storage and transport, LN_2 liquefiers of a new type, etc. as the Hony Director of the Advanced Centre of Cryogenic Research, Calcutta, a unique industry and application oriented institute established in 1979. I was the Founder President of Indian Cryogenics Council from 1975 to 1977 and am now running it as the Hony Director-General, to provide a common forum for Indian and foreign cryogenists to find ways and means to the multidisciplinary cryogenic development of the country. As Principal Editor, I am also publishing the *Indian Journal of Cryogenics* from 1976, of unique purpose, now running 10th volume (1985) on behalf of ICC. I have organized on behalf of ICC eight national symposia and four national seminars on cryogenics during 1975-1984. I also organized the International Conference on Cryogenics held during 10-13 December 1985 receiving wide support from all over the world. I also gave a lecture on 'Cryogenics in the service of the nation' at the Prof. K S Krishnan Memorial week of NPL in November 1983 and was awarded in Plaque of NPL[25].

In conclusion, I shall be guilty of stark ingratitude if I do not express my indebtedness to my host of students in the years 1947-85, for whatever success has fallen to my lot in my achievements. Most of them, about 50 in number, have received their PhD and/or DSc degrees and are posted in responsible positions in India and abroad. Some of them, notably Prof P Sengupta, my right hand, have made it possible to successfully set up and run the Indian Cryogenics Council and the ACCR, the summum bonum of my life in the service of the country.

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Bimla Buti

Most of the work done till recently, in general and in particular, related to space and astrophysical plasmas emphasized on the linear models. Because of the mathematical complexities involved, even though the observed phenomena demanded nonlinear analysis, the scientists had to restrict themselves to linear analysis. However, the situation is quite different now. There have been a number of attempts to study a variety of nonlinear processes; some of these are: Nonlinear waves—solitary waves, harmonic generation; Shocks; Double layers; Nonlinear mode coupling and mode conversion; Nonlinear saturation of instabilities; Nonlinear generation of d.c. fields; Coherent rediation from plasmas—Auroral Kilometric Radiation, Radio-Pulsar emission, etc.; Anomalous heating and acceleration of particles; and Nonlinear surface phenomena.

Over the last few years, we have put in our efforts in the study of the above-mentioned nonlinear and turbulent processes. These investigations were undertaken to interpret some of the observations made in laboratory, astrophysical and space plasmas.

Nonlinear analysis of the plasma is necessitated because of the following reasons:

(1) The perturbations may be intrisically large, e.g. in the case of solar flares, solar radio bursts, etc.

(2) To start with, the perturbations may be small, but because of some available source of energy, they may grow to finite extent.

The nonlinearities, besides giving rise to anomalous heating and acceleration, can lead even to turbulence. A turbulent system is necessarily nonlinear, though the reverse may or may not be true.

Solitons are stable solitary waves which arise when there is a balance between the nonlinear and the dispersive effects. However, these solitons are also strictly stable in one (space)-dimensional systems. In order to investigate the stability of realistic systems in three dimensions, a self-consistent three-dimensional (3-d) nonlinear Schrodinger equation is derived. Analysis of this equation shows that the collapse of plasma waves is possible only under certain restricted conditions unlike the earlier feeling that the collapse is a must in 3-d systems[1,2].

More often than not, the plasmas that one encounters both in space and in fusion devices are inhomogeneous (inhomogeneities may be small or large); they also have more than two species. The presence of multi-species in fusion plasmas arises because of impurities, whereas in natural

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plasmas this happens simply because of the complex composition. These inhomogeneities have been shown to play the role of collisions, which may be absent otherwise[3]. The presence of multi-species can even lead to some new nonlinear features[4–6]. For the first time, we had predicted that a plasma with hot and cold electrons (e.g. solar wind, terrestrial magnetospheric and laser plasmas) can sustain rarefactory (holes) solitons besides the compressive solitons[4]. Recent observations through satellite S3-3 have confirmed the presence of these rarefactory solitons, which subsequently because of reflection of electrons from these solitons, lead to ion-acoustic double layers observed in the region of 6000-8000 km height in the terrestrial auroral plasma.

By and large, pulsars are synonymous with the neutron stars. The magnetospheres of these neutron stars, because of the rotating strong magnetic fields, consist of relativistic plasmas. Accounting for the relativistic temperatures and relativistic speeds of the charged particles, we have shown that the relativisitc Langmuir solitons can occur and can act as a coherent source for the radiation. These Langmuir solitons, moving along the curved magnetic field lines, give rise to radio emission due to curvature radiation. This model can explain most of the observed features, namely the coherent emission, the linear polarization, and the pulse shape, etc., of the radiation from radio pulsars[7]. It is very interesting, on the other hand, to point out that the interaction of relativistic electromagnetic solitons with the plasma wave can even generate d.c. electric field[8]. This is indeed a new and novel mechanism for the generation of d.c. electric fields.

Large amplitude waves—in particular, Alfven waves—have been observed in the solar wind, in supernova remnants and also in the galaxy. These waves can occur in the form of envelop solitons[9]. These solitons can provide turbulent heating of plasmas and can act as a source of acceleration of charged particles. Similarly, the observed large amplitude whistler solitons in turn interact with the upper hybrid waves and produce coherent radiation in a much more efficient manner. This emission can very favourably account for the observed auroral kilometric radiation[10] and also the observed fine structure in solar radio bursts[11].

Recent satellites have observed the electrostatic turbulence in the interplanetary medium. The anomalous resistivity, due to this turbulence when properly accounted for, can explain a number of observed features. For example, the terrestrial magnetospheric boundary, which can be unstable in the absence of any turbulence, is perfectly stable in the presence of the observed turbulence. The period of oscillation of this boundary is in very good agreement with the one observed by the OGO satellite[12]. Similarly, the fine structure, e.g. helical waves observed in the cometary plasma tails can be interpreted in terms of the Kelvin Helmholtz instability of the interface between the solar wind plasma and the comet plasma. The presence of the observed turbulence, in the solar wind, introduces a critical distance beyond which only the helical waves can appear. Our model gives this critical distance, which is in excellent agreement with the observations[13–15].

While doing the systematic analysis of some of the nonlinear evolution equations like Korteweg de-Vries (KdV) and modified KdV (MKdV) equations, we find that these equations not only have real solutions, which are referred to in the literature, but also have complex solutions. We are looking into the physical implications of these complex solutions as well as the problem of the stability of these complex equations. The existing methods, namely the Inverse Scattering Method, Variational Principle and Liapunov Method, do not seem to work. For these stability investigations, we have to look for some new technique.

Another potential area, which is still virgin, deals with the surface phenomena in nonlinear dispersive media. Unlike the laboratory plasmas, the boundaries in the case of space and astrophysical plasmas invariably are free boundaries. So for making a self-consistent model, the dynamic nonlinear boundary conditions should be used. Of late, there have been some attempts to investigate the nonlinear surface waves, but unfortunately they cannot be extended to natural plasmas simply because they are restricted to static linear boundary conditions. We plan to look into this very interesting field to study the basic problems of interaction of solar wind with comet, planetary atmospheres, etc.

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S Chandrasekhar

Chandrasekhar's early work dealt with crystalline optical activity. He proposed a new and simple quadratic formula for the rotatory dispersion of crystals that are not optically active in solution. The most important case that he investigated was quartz which has been the subject of numerous studies since the early part of the last century. He showed that the rotatory power of quartz from the near infrared to the vacuum ultraviolet (representing a 40-fold increase) can be accurately expressed by a single term of the new type of formula (involving two adjustable parameters), whereas the conventional Drude equation requires at least 5 terms (or 10 adjustable parameters) to give a comparable fit. This single term is adequate to explain the dependence of the rotatory dispersion on temperature and pressure.

The possibility of such a 'quadratic' term occurring in crystalline optical activity was in fact recognized by Born and Goppert-Mayer in 1933. Chandrasekhar suggested a simple theoretical interpretation of the origin of this term on the basis of a coupled oscillator model. Subsequently, Agranovich presented a more general quantum mechanical derivation, and the formula is, therefore, referred to in the Soviet literature as the Chandrasekhar-Agranovich equation. These results stimulated further experimental studies and the equation has been applied to a number of other crystals.

Chandrasekhar pointed out the inadequacy of calculations seeking to explain the discovery of Bijvoet *et al* that crystals of $NaClO_3$ and $NaBrO_3$ having similar absolute configurations have opposite signs of optical rotation. He confirmed this by making detailed measurements of the rotatory dispersion of these two crystals and of mixed crystals of $NaClO_3$-$NaBrO_3$. His studies demonstrated that calculations of the optical activity in terms of *gross* atomic refractivities but neglecting the rotational strengths of the different absorption bands are necessarily inconclusive.

Chandrasekhar's next significant contribution was the theoretical proposal and the experimental verification of a new method of correcting for errors arising from primary and secondary extinction effects in the accurate determination of the structure factor of an X-ray reflection. The method involves the use of polarized X-ray and measurement of the integrated intensities of reflection for parallel and perpendicular polarization. Chandrasekhar experimentally demonstrated the feasibility of the method for crystals of arbitrary shape; he later showed that it is equally valid in terms of the generalized theory of X-ray diffraction from real crystals formulated subsequently by Zachariasen.

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Chandrasekhar was the first to point out that the standard expression for the polarization factor is not valid when the reflection is suffering from extinction effects, a fact that had been overlooked by C G Darwin in his famous paper on the theory of X-ray diffraction from imperfect crystals. Chandrasekhar's expression was derived later independently by Zachariasen who illustrated the importance of taking it into account in routine structure analysis.

For the past 25 years, Chandrasekhar's major work has been concerned with the study of liquid crystals. When he initiated this activity in Mysore in 1961, few scientists were even aware of the existence of these materials, and Chandrasekhar and his students formed one of the three or four isolated groups in the world that started systematic investigations into the physics of these states of matter. In 1971, Chandrasekhar moved (along with some students) to the Raman Research Institute, reorganized the laboratories of the institute and established a centre which is now acknowledged internationally as a leading school of research in this important branch of modern condensed matter physics.

The physics of liquid crystals is an interdisciplinary field involving continuum mechanics, statistical physics, theory of phase transitions and critical phenomena, optics of anisotropic media, molecular physics, crystallography, etc. Chandrasekhar's pioneering work in this area is acknowledged to have played a significant role in the resurgence of interest in the physics of these materials. His book *liquid Crystals*, published as a Cambridge Monograph on Physics, is universally acclaimed as a classic treatise on the subject. In p 40 of his book, Chandrasekhar had the foresight to write "The question of mesophases occurring in systems of disc-shaped particles is of fundamental importance". Probably, the most significant contribution of Chandrasekhar and his colleagues was the discovery in 1977 that relatively simple disc-like molecules can form liquid crystalline phases. These molecules form an entirely new class of liquid crystals, which have translational order in two dimensions and liquid-like disorder in the third. The physics of this class of liquid crystals is different in many respects from the classical liquid crystals of rod-like molecules, and the subject has now become an exciting field of study in several laboratories throughout the world.

Chandrasekhar has been an invited speaker in practically all major international liquid crystal conferences in the last two decades. He is a Fellow of the Royal Society of London (being the first person to be so honoured explicitly for contributions to the physics of liquid crystals) and has received several other honours and awards in recognition of his work.

Chandrasekhar is an Editor of *Molecular Crystals and Liquid Crystals*, an international journal published by Gordon & Breach. He is currently the Chairman of the International Planning and Steering Committee for International Liquid Crystal Conferences.

Selected Publications

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S D Chatterjee

In the field of nuclear physics, investigations on the spontaneous fission of uranium were carried out independently during the second world war (1940-1944) at the Bose Research Institute, Calcutta, without any knowledge of similar work being conducted by Petrzhak and Flerov in Russia. Measurements were made of the half-life of spontaneous fission of uranium, detection and measurement of number of neutron emissions from uranium and chemical identification of stable fission products from an indigenous uranimite mineral, whose age was determined to be ~836 million years (by measurement of U/Pb ratio). The experimental results were reported in a few papers[1-3].

In the field of radio-chemistry too, important work was done[4]. Radioactive ^{60}Co was chemically isolated for the first time, utilizing a variation of Szillard-Chalmers method, after irradiating a chemical complex compound of sodium cobalticyanide with a meagre 60 mc (Ra + Be) neutron source. Incidentally, this work[5] was noted in *Progress in Nuclear Physics*, Vol. I, edited by O Frisch. It demonstrated that there was no essential difference between normal co-valency and co-ordinate co-valency and received special mention in the annual report of the *J chem Soc, London* for the corresponding year.

In the field of cosmic rays, several important papers were published[6]. Pioneering measurements were carried out in India[7-9] following similar measurements initiated by E Fünfer in Germany, and by S A Korff in USA. This work represented the first recording and measurement of cosmic ray bursts in India.

In the field of environmental radioactivity, a number of important papers were published[10-13]. Some work was also done in the field of radiophysics and electronics[14,15].

The new method introduced an accuracy of ±0.1 km and was found to be highly suitable for investigating the fine structure of the ionosphere layers and the influence of tidal effects on them[16,17].

Utilizing a heated ex-centric wire within a Geiger counter and counting the individually emitted electrons, O W Richardson's equation for thermionic emission has been verified at lower temperature than was done before.

In the field of solid state physics, two particular lines of investigation were pursued:

(A) Exploration of the behaviour of the so-called *n*-type and *p*-type coherers utilized by Sir J C Bose at the beginning of the twentieth century for the detection of

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e.m. radiation of mm wavelengths, when thermionic tubes were unknown. Some interesting results were reported[18-20].

(B) Electrets: Extensive work has been done to investigate the basic properties of various types of electrets, viz. thermo-electret, magneto-electret and photo-electret, by measuring the time variation of their surface charge, dielectric constant, magnetic susceptibility, specific conductance and depolarization current. Some interesting papers were published[21-23].

Exploration in the field of geophysics was undertaken at the instance of Prof. S N Bose. It commenced with the measurement of radon content in thermal spring waters at Bakreswar, District Birbhum, West Bengal and culminated in the discovery of helium as a rich component of the natural gas emanating spontaneously from some thermal springs scattered all over India. The project has now been taken over by the Atomic Energy Commission and regular work is being carried out at some sites and at the variable Energy Cyclotron Centre at Calcutta. Quantitative measurements are now in progress for the determination of isotopic abundances of noble gases like argon, neon, xenon and krypton detected as micro-components of the natural gas emitted spontaneously from thermal springs. A few papers were published[24-27]

Our final quest is for the location of the source of helium production within the bowels of the earth. The Russians are of the opinion that it is a legacy of some kind of thermonuclear reaction still active within the earth. To ascertain how far this is true is our present objective.

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R Chidambaram

There are two main lines of research which Chidambaram initiated at the Bhabha Atomic Research Centre; these have grown over the years. The more recent one relates to high pressure and shock wave physics and the other one to neutron crystallography.

In the former field, his group has done extensive work on static high-pressure phase transformations, developed theoretical models for equation of state of condensed matter at ultra-high shock pressures and carried out computer simulation studies of shock-induced phenomena in the context of peaceful nuclear explosions. In neutron crystallography, he has studied hydrogen-bonded crystals, including molecules of biological interest, developed new hydrogen-bond potential functions, and introduced for the first time in India indigenous designs of diffractometer automation culminating in computer control.

In *shock-wave physics*, Chidambaram and his collaborators have developed a new theoretical model for the equation of state of condensed matter in the 'intermediate' (5 to 100 Megabar) region[1]. In this difficult pressure region, where thermal and pressure ionizations change the valence state of the atom, this model utilizing a modified Saha's ionization equation has been acclaimed by leading workers to be the best currently available in the field. Based on this work, a review article has been published in "*Physics Reports*"[2] about which the editor Prof. ter Haar of Oxford has communicated the following comment of the referee: "I thought the review was very good in a number of ways. First, it brings the subject up-to-date....The authors, having worked in the field, speak with some personal authority". Earlier, they had attempted one of the few first-principle calculations anywhere of the shock Hugoniot equation of state in metals; the calculation on aluminium[3] resolved a long-standing controversy in experimental data from two groups in UK and USSR by showing that the electronic Grüneisen parameter departs considerably from the value used conventionally in analysing shock-compression experiments. The future direction of this work will be to establish experimental facilities, e.g. the gas-gun, to undertake precise experiments on material properties under shocked conditions.

In the field of *peaceful nuclear explosions*, Chidambaram's group has built up extensive capability in computer simulation of PNE phenomenology. The results obtained from Pokaran PNE experiment have been studied exhaustively[4] and a computer simulation has explained many interesting features of this experiment[5].

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Chidambaram and his collaborators have established experimental facilities for studying *static high-pressure phase transformations* using electrical resistivity and X-ray diffraction as the probes[6]. The enhancement of the latter set-up, with a rotating anode X-ray generator, computer-linked energy dispersive detector and laser ruby fluorescence probe for calibrating the pressure measurements, shall soon make it one of the best in the world. Among many studies carried out so far, the most significant are perhaps those on the very interesting high-pressure omega phase in Group IV metals like Ti, Zr, Hf and their alloys. These studies have revealed important features regarding the kinetics and structural aspects and about the electronic structure and stability of this phase and led to a review article in "*Progress in Materials Science*"[7].

In neutron crystallography, Chidambaram's early work on nonlinear hydrogen bonds in hydrated crystals[8] and on the lone-pair coordination of hydrogen-bonded water molecules in crystals[8] are very widely cited in the literature; the latter reference has well over a hundred citations in the literature and it still continues to be cited. He and his collaborators have developed new potential functions for non-linear O-H-O hydrogen bonds[10] and these have been extended to N-H-O bonds between peptide groups[11]; the latter have proved very important in studies of conformation in macromolecules. His neutron diffraction studies on the molecular structure, conformation and hydrogren bonding in amino acids[12] have been widely referred to in recent reviews and other articles in the context of protein structure modelling. His more recent interests in neutron diffraction have been in the study of low temperature phase transitions, particularly those with unusual features[13].

The high-precision neutron diffraction studies carried out by his group have been possible because they have pioneered the design and construction of the first (and so for the only) completely indigenous computer-controlled neutron and X-ray diffractometers in the country[14].

The future direction of Chidambaram's research in neutron crystallography will be towards the study of phase transitions on the one hand and on biological molecules on the other[15]. These studies will get a great fillip now that the new high-flux reactor DHRUVA has gone into operation in Trombay.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R R Daniel

The important research contributions of Daniel can be summarized under three major heads: (1) Study of high energy nuclear disintegrations using cosmic ray collisions in nuclear emulsions; (2) Studies on the nature of primary cosmic radiation; and (3) Infrared astronomy.

(1) Cosmic Ray Produced Nuclear Interactions

These studies were carried out primarily during the years 1947 to 1955, when particle accelerators had not reached the threshold for strange particle production or multiple meson production. Among various findings, an important contribution here was the reporting of the first example of nuclear interaction of K-mesons. A valuable piece of work on high energy interactions produced by cosmic ray helium nuclei gave interesting information on the characteristics of interactions between helium nuclei of energy greater than about 5 GeV/nucleon and heavy nuclei of emulsions. Another investigation of considerable merit on interactions produced by cosmic ray particles of energy close to 1000 GeV/nucleon is the identification of the persisting baryons among the emerging particles and its application in analyses relating to nuclear interactions at high energies; this was carried out in the early sixties. These and other contributions of the TIFR group using nuclear emulsions for the study of high energy interactions earned for the group a high international standing.

(2) Studies on the Nature of the Primary Cosmic Radiation

These researches were carried out during the years 1955 to 1975. Contributions under this topic were made partly from studies with nuclear emulsions flown to high altitudes using giant polyethylene balloons launched from Hyderabad and partly from interpretative and theoretical studies. Under this topic, two major studies were carried out. The first related to the nature of the nucleonic component of cosmic rays. In this field, an important contribution was the first calculation on the production of radio isotopes in cosmic ray collisions in interstellar medium. Our early work was later elaborated and studied in depth by workers from all over the world. Another contribution relates to the first observation on the even-odd effect of cosmic ray nuclei with charges between 6 and 20. Our early calculations for the age of the cosmic rays has also stood the test of time.

The second major contribution is the first observations on the high energy electron component of the cosmic rays of energy greater than 10 GeV and going up

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to about 100 GeV. This opened a new avenue for studying a number of important topics, such as the propagation of cosmic rays in interstellar medium, the confinement of cosmic rays, the age of the cosmic rays, and the quantitative connection between energetic electrons in space and the galactic background radio noise. A number of such in-depth interpretative studies were carried out over a period of five years; these resulted in a series of publications of great significance and importance.

The following are a few other investigations which also led to important findings. Observations from a balloon platform over Hyderabad on cosmic gamma rays of energy in the MeV range gave a reliable spectrum in this energy range and demonstrated that a hump claimed by some workers is either absent or of much smaller amplitude. Pioneering work was carried out on the detection of energetic neutrons during times of intense solar activity. The first space observations for solar neutrons were attempted in an experiment carried out by the first Indian satellite, Aryabhata. However, owing to a general power failure on-board, the experiment worked only for a few days. While we got useful data on albedo neutrons, we could not detect solar neutrons. However, a few years later, a group in USA was successful in getting a longer satellite exposure and made the first observations. A third investigation of importance is a detailed calculation of secondary cosmic ray electrons and photons in the atmosphere for all latitudes and atmospheric depths.

(3) Infrared Astronomy

Recognizing the constraints on making significant contributions in cosmic rays using balloon platforms, a few of us changed our field of study around 1975 to infrared astronomy, which is now a new astronomical window with great potentials. Even here, our emphasis is in far infrared astronomy (50-200 μm) which again needs a space platform, and in our case balloon experiments. For this purpose, a 1 m balloon telescope and associated instruments have been developed. It includes a sophisticated radio controlled three-axes stabilized pointing system with a star tracker and rate gyroscopes having pointing accuracy of about 20 arcsec, ground control by radio and telemetry for data transmission and a liquid helium cooled IR detector system. The payload has been successfully flown twice and interesting data on planet Saturn and extended IR sources have been obtained. The payload with improvements is now ready for further balloon ascents. There are great possibilities for us in this area in the years to come.

Work has also been started at IR wavelength of 1-3 μm using IR detector systems at the 1 m telescopes at Kavalur (IIA) and Rangapur (Osmania University). A number of interesting observations have been made so far on many celestial objects strongly emitting in infrared.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B A Dasannacharya

Dasannacharya started his scientific career in 1958 at the present Bhabha Atomic Research Centre, then known as the Atomic Energy Research Establishment, Trombay. He passed his BSc examination from Banaras Hindu University where he obtained the Devasthale Prize for standing first in physics in 1957. He then joined the Training School of the Atomic Energy Establishment. From 1958, he started working with Dr P K Iyengar, who was then initiating neutron diffraction and neutron scattering research at Trombay. He collaborated with Drs P K Iyengar and N S Satya Murthy in setting up the first neutron diffraction and neutron inelastic scattering spectrometers at Trombay, at the Apsara Reactor working then at 250 kW[1]. Measurements of phonons from iron formed the subject matter of his MSc thesis. He also performed magnetic diffraction experiments leading to the determination of antiferromagnetic structure of $FeSn_2$[2].

In 1961, as a Colombo Plan Fellow, he went to the Atomic Energy Canada Ltd at Chalk River to work with Prof B N Brockhouse. There he made one of the then most extensive measurements of neutron scattering from liquid argon near its triple point (with Dr K R Rao). This was a time of some confusion in the field of neutron scattering. Several attempts were being made to demonstrate the existence of well defined phonon like modes in liquid argon using time-of-flight data which led to an artificial 'peak' in neutron experiments. Experiments on liquid argon, done at Chalk River, were the first sufficiently extensive time-of-flight cum triple axis spectrometer measurements which could be properly put on constant momentum-transfer scale to avoid the experimental artifacts mentioned earlier. This allowed the determination of space and time dependent self and pair correlation functions, $G_s(r,t)$ and $G_d(r,t)$, for liquid argon[3]. These results have been corroborated by later experiments on isotopically separated samples.

On return to Trombay, he started neutron scattering experiments on low temperature molecular liquids, the first one to be studied being CH_4. These experiments were done using a rotating crystal spectrometer which was installed at Trombay during 1962-63 by Dr G Venkataraman and his colleagues. With the good resolution available on this spectrometer, it was possible to show that rotations of CH_4 are hindered in liquid methane near its triple point[4]. These measurements were extended to liquid CD_4 and the two measurements together, along with earlier Raman and IR measurements, led to the establishment of a quantitative relationship between neutron scattering on the one hand and

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Raman scattering and infrared absorption on the other. It was then possible to explain the neutron scattering results using orientational correlation functions up to fourth order[5]. Using the inverse process, it was later possible to derive the first order orientational correlation function in liquid NH_3[6].

During this period, it was gradually being realized by the workers in the field that stochastic motions of particles in solids would also lead, in a neutron scattering experiment, to broadening of the elastic line, which could be used for examining the nature of reorientations in solids. This programme started by Venkataraman[7] was followed up extensively by Dasannacharya and Goyal, who studied a number of pure and mixed ammonium compounds like $(NH_4)_2SO_4$, $[K_x(NH_4)_{1-x}]_2SO_4$, NH_4LiSO_4, $(NH_4)_2$ BeF_4 and $(NH_4)_x$ K_{1-x} (Br,I). The studies on the halides gave detailed information on the reorientational behaviour of a tetrahedral molecular group residing in first neighbour octahedral surroundings[8]. The experiments on double sulphates and fluo-beryllate (all of which show phase transition) give information on the rate and geometry of reorientation of the ammonium ion[9]. Since some of these substances contain two NH_4^+ ions per molecule, it is not possible to differentiate their orientational dynamics in a simple way. Goyal and Dasannacharya have shown how this can be done at least in some of the simpler cases[10]. The experiments on the line broadening were supplemented by inelastic scattering experiments enunciating the molecular vibrational frequencies. These studies conducted on amino acids and crystal hydrates (apart from ammonium compounds mentioned earlier) have given information complementary to infrared and Raman scattering experiments. The group at Trombay was the first to use the polarization dependence of incoherent inelastic scattering to characterize liberations of water molecules in crystal hydrates[11].

Most of these inelastic scattering measurements were made on the so-called "Filter Detector Spectrometer" which has been used extensively at the Bhabha Atomic Research Centre, since it is a spectrometer particularly suited for small reactors like CIRUS, with neutron flux in the range $1\cdot5 \times 10^{13}$ n/cm^2 sec. It was believed that these instruments are unsuitable for measurements of phonon dispersion relations, especially if they have a large slope. This was shown to be not so by Thaper, Dasannacharya and Iyengar[12], who demonstrated the power of this instrument in measuring phonon dispersion relations accurately. This led to a direct experimental proof of the breakdown of local pseudopotential theory for Be[13].

During 1974-75, dasannacharya worked at the Institute fur Festkoperforschung der Kernforschungsanlage, Jülich, where he successfully measured phonon modes in normal liquid ^{4}He, which was explained through generalized hydrodynamic theory[14]. He, at this time, also proposed a new quick method of measuring the temperature dependence of the diffusion coefficient of some liquid crystals and did feasibility experiments to prove the validity of this method.

Recently, he proposed a novel method of detecting neutrons in a narrow energy window whose width can be varied continuously from about 15 to 40 μeV[15]. This led to the development of the ΔTwindow spectrometer, which was fabricated at Trombay and is now installed at the spallation neutron source, ISIS, of the Rutherford Appleton Laboratory, UK. This spectrometer has bridged a gap which existed in the energy resolution in the available meutron spectrometers.

At present, Dasannacharya is involved in the development of a cold neutron source for the Dhruva reactor, a small angle neutron scattering instrument, and a multi-angle reflecting quasi-elastic scattering spectrometer with a two-crystal monochromator. His experimental interests continue in the areas of study of stochastic motions in dynamically/statically disordered solids and structures of disordered system.

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A S Divatia

Divatia has been involved with accelerator development and accelerator physics in recent years as Director of Variable Energy Cyclotron Centre of the Bhabha Atomic Research Centre, Calcutta. His association with the cyclotron began with the preparation of the project report and then continued with the execution of the project of constructing the Variable Energy Cyclotron and finally organizing the research programme of the accelerator carried out by scientists all over India. This 224 cm VEC with a project cost of Rs 10 crore was built entirely indigenously using only the minimum foreign exchange to the extent of 10% of the total cost. Major jobs involved in constructing the cyclotron were:

(*i*) Fabrication of the 260 tonne magnet at Heavy Engineering Corporation, Ranchi.

(*ii*) Fabrication of the magnet coils at the Bharat Heavy Electricals Ltd, Bhopal.

(*iii*) Fabrication of the resonator tank at the Garden Reach Shipbuilders and Engineers, Calcutta.

(*iv*) Fabrication of the radiofrequency panels, the dee and dee stem at the Central Workshops, BARC, Bombay.

(*v*) Fabrication of the deflector at the Central Workshops, BARC, Bombay.

(*vi*) Fabrication of the main vacuum system at the Technical Physics and Prototype Engineering Division, BARC, Bombay.

(*vii*) Fabrication of the Beam Transport System, including two switching magnets, one analysing magnet and quadrupole magnets.

(*viii*) Setting up research facilities, such as scattering chamber, detectors and target facility, electronics facility, magnetic spectrometer, radio-chemistry laboratories, etc.

After the operation of the cyclotron, users from all scientific institutions and universities in India have started utilizing the cyclotron for a variety of multidisciplinary experiments and important results have started coming in. The construction of the cyclotron contributed very significantly to the development of many technologies in India and many 'firsts' have been incorporated, e.g. the 89 cm diffusion pumps for the main vacuum system were built for the first time in India for the cyclotron. Interaction with large industries as well as small industries has been stimulated.

Earlier, Divatia had been responsible for installing the 5.5 MeV Van de Graaff accelerator at Bhabha Atomic Research Centre, Bombay and starting a programme of research in nuclear reactions. The installation of the Van de

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Graaff accelerator and the research using charged particle reaction generated a core of personnel experienced in accelerator development and nuclear physics.

Immediately after joining the Bhabha Atomic Research Centre, Divatia carried out the installation of a 400 keV Van de Graaff accelerator at the Tata Institute of Fundamental Research using totally indigenous components. This also generated personnel experienced in accelerator development.

While working for his doctorate degree at the University of Wisconsin, Divatia developed the first continuously operating Getter-ion pump for producing ultra-high vacuum and developed various systems of electrostatic accelerators. He also carried out some of the earliest work on coulomb excitation of nuclei using the 4 MeV Van de Graaff accelerator at the University of Wisconsin.

Divatia has been active in the organization of professional physics societies. He initiated the formation of the Indian Physics Association and was its founder Secretary for a number of years. He has also been actively involved with the Indian Physical Society, of which he is the President at present. He is also an active member of the Indian Vacuum Society.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

A K Dutta

Dutta had his early education at Dacca University terminating with a first class first in MSc. He began his research career in the field of molecular and atomic spectroscopy at the University of Allahabad under Prof. M N Saha. Several of his papers were published in *Proceedings of the Royal Society, London*. He also submitted this work to the Dacca University for DSc degree which was awarded to him in 1933.

In 1936, he was awarded a post-doctorate fellowship of the Deutsche Akademite in Germany and worked under Prof P Debye, N L, at Kaiser Wilhelm Institute, Berlin Dahlam in the field of ultrasonics. He published several papers on this subject in *Physikalische Zeitschrift* and *Zeitschrift fur Physik*. He returned to India in 1938 and worked in the field of ultrasonics at the Bose Institute, Calcutta, and in the Universities of Delhi, Dacca, Calcutta and Orissa.

During 1951-60, he was Mayurbhanj Professor of Physics, Utkal University, Cuttack. He was Palit Professor of Physics at Calcutta University during 1961-68. In Calcutta, his research interest was mainly on nuclear structure of matter. He published his papers in several national and international journals, including the *Indian Journal of Physics, Journal of Theoretical Physics* (Japan); and *Physical Review* (USA).

Dutta was President, Physics Section, Indian Science Congress Association in 1959. In his Presidential Address, he reviewed his contributions on the absorption of ultrasonic waves in liquids. He was invited to the international conference on ultrasonics, in 1948. He was also invited to act as a referee to the Guggenheim Memorial Committee of America for giving opinion on a reputed American worker on ultrasonics in 1951.

In 1973, Dutta published a book on Electromagnetism, Electron Theory and Special Theory of Relativity (Macmillan & Co.).

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A K Ganguly

Ganguly did his MSc (pure chemistry) from Calcutta University in 1940. He was admitted to the degree of Doctorate of Science of the same university in 1948 on the basis of his thesis on 'Ion exchange in silicate minerals related to soils and clays'. He carried out research in three broad areas: (1) Radiation chemistry—physics and chemistry of fission of heavy nuclides; (2) Radiation physics and theory of transport of high energy radiation through matter; and (3) Thermo-luminescence for radiation dosimetry.

Ganguly has to his credit notable contributions in the following fields: Ion exchange reactions and kinetics of marine chemical reactions; water movement in coastal environment; diffusion and dispersal of liquid radioactive effluents in fresh waters and coastal waters; environmental weathering of superficial rocks; atomic absorption spectrophotometry; determination of trace elements in environmental and biological systems; atmospheric pollution and control measures for it; organometallic interactions in aquatic environment; complexing properties of marine sediment humus; safety evaluation of designs of nuclear installations; and physics and chemistry of fission of heavy nuclides and transuranic elements.

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S N Ghosh

Ghosh has a strong background in applied physics and has made substantial contributions in different branches of this field. His work has been concerned mainly with upper atmosphere and space problems, applied spectroscopy, collisional problems and e.m. wave propagation.

Upper Atmosphere: After consulting many thousand papers, books and data sheets, Mitra compiled a classical book on the upper atmosphere[1]. It has run into two editions. Ghosh's contribution in both the volumes is significant.

Sodium in the Upper Atmosphere: Spraying of Na, etc. from rockets is an important and complicated technique for exploring the upper atomsphere. This technique was originally suggested by Prof. Bates. Its practical aspect was perfected by scientists of Air Force Cambridge Laboratory, Boston, USA, Ghosh being one of them[2,3].

The origin of sodium in the atmosphere has been a subject of considerable speculation. The question is whether it is of terrestrial or extra-terrestrial origin. Several scientists have proved that it is of extra-terrestrial origin. Ghosh is one of them[4]. He obtained the input flux of Na in the atmosphere.

Paramagnetic Resonance in Uranium Compounds: The investigation of paramagnetic resonance is important in many respects. Paramagnetic resonances in uranium compounds were obtained for the first time by Ghosh and his associates using microwave technique[5]. He obtained resonances in UF_3 and UF_4.

Structure of Ozone: Determination of the structure of ozone is very important. Using different techniques, chemical and spectroscopic, no conclusive result was obtained and the problem remained unsolved for a long time. One of the groups which finally determined it using microwave technique and special waveguide is Ghosh and his associates[6].

Charge Exchange Process: The charge exchange process is an important collisional process involving no momentum transfer and having very wide application in geophysical and astrophysical problems. It is important to study this process experimentally and this was done using a mass spectometer as the ion source for a large number of reactions[7,8]. Cross-section versus energy relationship has been studied. It has been shown that near resonance condition may be attained under different conditions.

Space Communication: For space and satellite communication, radiations having waves in the GHz region are used. These waves are absorbed and scattered by terrestrial and other planetary atmospheric constituents and by particles in the inter-

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Formerly, Sir Rashbehary Ghose Professor of Applied Physics, Calcutta University; *Residence* : 102, Southern Avenue, Flat 2B, Calcutta-700029.

planetary and interstellar space. Ghosh has developed a method for obtaining the absorption after taking into account the density, pressure and temperature variations of planetary atmospheric constituents and microwave spectroscopic data and using quantum mechanical expression for absorption[9,10]. This method is of great importance in space communication.

Secondary Electron Emission by Ion Bombardment: As ions emanating from a source pass through a target, secondary electrons are emitted. Ghosh has made a strong ion source using a mass spectrometer to bombard metal and semiconductor targets. The characteristics of secondary electron emissions are obtained. Also, a plausible theory of such emission was presented[11,12].

Microwave Spectra of Gases: In addition to well known methods of excitation of spectra, gases can be excited to emit spectra by microwave discharge. During such a discharge, the molecules are ionized, excited and may be dissociated to produce atoms. The dissociated atoms being very reactive readily combine with particles producing in many cases excited atoms and reaction glow. These reactions are important not only for elucidating the basic information of such reactions but also for increasing our knowledge in other fields, viz. the upper atmosphere, combustion, etc.

A very efficient experiment was set by Ghosh and his associates using a strong microwave source. Extensive work was carried out on microwave discharge of atmospheric gases and collisional processes between dissociated atoms and molecules[13].

Minor Constituents of the Atmosphere: Minor constituents of the atmosphere play an important role. Study of their altitude distribution by direct methods is quite involved. Using a rocket borne quadrupole mass spectrometer, Ghosh and his associates determined the altitude distribution of N atom in the atmosphere[14,15].

Spectra Excited by Proton Bombardment: For understanding many geophysical problems, it is necessary to know the nature and characteristics of the spectra excited by accelerated protons. For such investigation, a strong proton source of the smoke, Rees, Good type, was set up. The accelerated protons were then made to bombard gases and the excited spectra were analysed for application to geophysical problems[16,17]. The spectra were then compared with those produced by spark and microwave discharge.

Airglow: Although airglow has been studied extensively during the last half a century, there are many odd problems which require special studies. For example, the variation of a certain airglow line intensity with sunspot numbers and solar flares required observations over a long period and at a particular time respectively. These have been observed by Ghosh[18].

It has been recently observed that 5893 A and 5577 A line intensities attain peak values a few minutes after ground sunset and at the same time the sodium density is enhanced. These appear both in evening and morning twilights. Such a correlation has an important bearing on airglow excitation processes. Explanations for these phenomena were presented by Ghosh.

Effect of Motion of Atmospheric Gas Distribution: The expression of distribution of gases in the atmosphere is very important. A complete expression for such distribution was obtained by Ghosh[19].

$$\rho = \rho_0 \exp - \int \frac{mg}{KT} + \frac{I}{T}\frac{\delta T}{\delta z} + \frac{m}{KT}\left\{\frac{mg}{KT} + \frac{\delta T}{T\delta z}\right\} v^2 \, dz$$

where υ is the velocity of waves. Other terms have the usual significances.

The three terms on the right hand side correspond to density variation due to gravity, temperature and motion in the atmosphere respectively.

Interstellar Molecules : The molecules in the interstellar space are known as interstellar molecules. They form a rapidly growing modern field of study. Because of the peculiar conditions to which these molecules are subjected—very low density, large radiation field, and very low kinetic temperature—it may appear that very few molecules can be formed in space. Yet more than hundred molecules have been detected and the number is increasing at a rapid rate.

From a detailed study, Ghosh and his associates concluded that ion-molecular reactions is the main process for the formation of these molecules[20]. Life related molecules were investigated in space which gives support to the alternative view that life may have originated in space and then transported to earth[21]. Also, detailed study has been made whether communication through space will be interfered by the presence of these molecules.

mm Wave Propagation: Millimetre wave propagation and propagation through fibre optics hold high promise for future communication. Propagation of mm waves having large bandwidth around 94 GHz, which lies in the window was studied in detail from the point of view of its applicability for future communication.

Flowgraph: Flowgraphs, specially of the Chan-Mai graph, which hold high promise for efficient circuit analysis were studied in great detail by Ghosh and his associates[22,23].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P S Gill

Gill's research career began while he was a graduate student at the Department of Physics, University of Chicago. Prof. A H Compton's laboratory concentrated on the field of cosmic radiation, at that time the foremost field of research in physics.

Gill's main contributions were on (a) variation of cosmic rays with respect to time (seasonal, daily, 27-day period) and with azimuth, (b) the latitude effect of cosmic rays at sea level and at heights of 33000 ft above sea level, and (c) study of cosmic ray bursts and their frequency as a function of energy. The results of the last mentioned study were presented at the international symposium on cosmic rays held in June 1939 at the University of Chicago. This study conducted along with Marcel Schein indicated the first concrete possibility of measuring the spin of the muon which has a spin of 1/2. The theoretically calculated curves given by Oppenheimer and also by Christy and Kusaka are in agreement with experimental curves, which forces the conclusion that the bursts are set off by mesons of spin 0 (or at most of spin 1/2). This work has been extensively referred to in literature.

In nuclear physics, Gill carried out experiments with his colleagues and students on 43-day isomer of cadmium (115), decay of polonium-210, radiations from the decay of ^{182}Ta, thermal neutron cross-sections for producing some isomers, and detection of radioactive fallout.

In instrumentation, studies were carried out on externally coated pyrex G-M counters, frequency meter, improved decimal digital read-out, etc.

Since 1978, Gill has been engaged in improving and manufacturing record/play-back and erase magnetic heads. In magnetic heads, India has attained technological self-sufficiency.

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Chairman, Universal Magnetics (P) Ltd., Sector 19A, Chandigarh-160019.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Govind Swarup

During the first ten years (1953-1963) of his research career, Swarup made a number of major contributions to the field of solar radio astronomy. His discovery of type U solar radio burst, studies of Quiet Sun at centrimetre and decimetre wavelengths and a gyroradiation model proposed for explaining the slowly varying component are noteworthy contributions. During this period, he also developed a new technique for phase adjustment of large antennas. This principle has been used for phase monitoring and local oscillator distribution in almost all the radio interferometers and synthesis radio telescopes set up in various countries over the last 25 years.

During 1963-1970, Swarup conceived, designed and got fabricated a 530 m × 30 m steerable cylindrical radio telescope of a unique design at Ooty in South India. The radio telescope was placed on a suitably inclined hill to allow steerability in hour angle and was conceived by him for exploiting the method of lunar occultation. It provided for the first time high resolution angular data (1 to 4 arc sec) for over 1200 weak radio sources, particularly at metre wavelength. This data has led specifically to over 40 research papers and 4 Ph D theses by the Ooty group. He has guided a total of 14 Ph D scholars in the field of pulsars, interplanetary scintillation, radio galaxies, quasars, cosmology and radio astronomy instrumentation. The Ooty group, headed by him, has published about 250 research papers in radio astronomy over the last 15 years. Swarup's own contributions have been in the field of extra-galactic radio astronomy and cosmology. Particularly, he established an angular-size flux-density relation for extragalactic radio sources, which along with angular size counts showed that not only was the density of radio sources higher at earlier cosmic epochs, but their linear size was also smaller. These results provided an independent evidence against the steady state theory. It has now been shown clearly that the linear size evolves with redshift and not luminosity.

Recently, he has made major contributions to the setting up of a 4-km synthesis radio telescope operating at 327 MHz. He has now started working on the construction of a giant metre-wavelength radio telescope consisting of 34 steerable parabolic cylinders, each of size 100 m × 35 m, to be set up near Pune in Western India during 1985-90.

In summary, Swarup has been responsible principally for organizing a major radio astronomy group in India.

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P Hariharan

Hariharan has made major contributions in physical optics, more specifically in the fields of interferometry, holography, laser speckle and image processing.

At the National Physical Laboratory, New Delhi he was responsible for the development of several new types of interferometers, including lateral shearing interferometers and a radial shearing interferometer for testing optical systems, as well as three-beam and double-passed interferometers for very accurate measurements. Another significant advance was the double-passed Fabry-Perot interferometer. He was able to demonstrate the increased contrast and resolution that could be obtained with this instrument. Its advantages for studies of weak satellites of strong spectral lines have been recognized and instruments based on this principle are used widely for the study of Brillouin spectra.

As Director of the laboratories at Hindustan Photo Films (1962-1971), Hariharan was responsible for quality control, import substitution and new product development. During this period, he also worked on techniques for the production and processing of high-resolution photographic materials for holography. A new method for measurements of the modulation transfer function (MTF) of photographic materials using laser speckle patterns developed by him was presented at the International Congress on Photographic Science, Moscow, in 1970.

At the Indian Institute of Science, Bangalore (1971-73) and after joining the CSIRO Division of Applied Physics in 1973, Hariharan made several major contributions in the fields of holography and laser speckle. These included studies of the loss of resolution and image contrast with area multiplexing and speckle reduction techniques, as well as a detailed analysis of the statistics of speckle produced by a rough metal surface. Another achievement was the development of new techniques for multicolour holographic imaging. These represent a major breakthrough in the field of display holography and have found wide use in USA and Europe.

Another area in which Hariharan has made substantial contributions is image processing. His work led to new optical techniques for image coding and pseudocolouring and the development of a hybrid (optical/digital) processor for texture discrimination.

More recently, Hariharan has been leading a programme in the field of electro-optics. One project is aimed at developing improved methods for holographic

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nondestructive testing, by applying new techniques of electronic phase-stepping interferometry. The method permits very fast and accurate measurements of vector displacements and was described by Hariharan in an invited talk at the Gordon Research Conference on Holography and Optical Information Processing held in USA in June 1984. This technique should be very useful for strain analysis, since it overcomes most of the practical problems associated so far with holographic interferometry.

Hariharan has also been studying the use of digital techniques in high-precision interferometry. One application has been in the production of a solid Fabry-Perot etalon for Sacramento Peak Observatory. Another application has been in conjunction with a radial shearing interferometer for the meaurement of aspheric surfaces, which are now being used more and more widely in new lens designs.

Hariharan has more than 130 publications in international scientific journals. He has written a major review on 'Colour Holography' for the well known series '*Progress in Optics*' and two books, '*Optical Holography*' (Cambridge University Press, 1984) and '*Optical Interferometry*' (Academic Press, 1985).

Hariharan is a Fellow of the Institute of Physics (London), the Optical Society of America, the Indian Academy of Science and the Indian National Academy of Science. He was on the Editorial Advisory Board of "*Optica Acta*" from 1973 to 1979 and is currently on the Editorial Advisory Panel of "*Optics Letters*". He is Chairman of the National Committee for Optics and a member of the National Committee for Physics of the Australian Academy of Science. In 1984, he was elected a Vice-President of the International Commission for Optics.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P K Iyengar

In 1952, when Iyengar began his career, nuclear energy institutions the world over were in their infancy. A 1 MV Cockroft-Walton accelerator (at TIFR) was the only instrument available for any work in this field in India. Using this facility, Iyengar got his grounding in the detection of nuclear radiations, building electronics required for counting of nuclear particles and making neutron measurements. His earliest research publications are in nuclear reactions with 14 MeV neutrons, slowing down of neutrons in different media and fabrications of electronic pulse height and time analysers. This introduction to diverse aspects of nuclear research in his early career was responsible for the development of his wider perspectives. For a brief period of 15 months during 1956-57, he worked with Dr Brockhouse at Chalk River. He not only learned the techniques of neutron spectroscopy, but also made outstanding contributions on phonon measurements in germanium, one of the first detailed measurements and interpretations in terms of the interatomic force constants.

In the late fifties, when Apsara became available as a thermal neutron source, Iyengar had already made preparations to embark on a programme of solid state research, keeping in mind the potentialities offered by the larger CIRUS reactor which was under construction. Here again, he saw the importance of thermal neutrons in studying different aspects of condensed matter and launched a major programme of neutron beam instrumentation, so that when CIRUS became available, totally Indian-built neutron spectrometers were ready to work on crystallography, lattice dynamics, magnetism and molecular spectroscopy. An important option chosen by Iyengar regarding the use of the crystal spectrometer technique in preference to the then popular time-of-flight technique was a stroke of genius. In fact, the wisdom of this choice (which was realized later by researchers in America and Europe) can be appreciated if one sees the neutron instruments in use at the world's high flux reactors today.

Iyengar can today be described as one of the founders of neutron spectrometry in India. His innovations in neutron scattering techniques like the Multi-Arm Neutron Spectrometer and the "Window Filter" Spectrometer are standard tools for neutron beam research all over the world today. The latter instrument was an innovation in 1963, but its full potential as a high resolution instrument was proved when it was set up at the Rutherford Laboratory in UK and worked as expected during the first few minutes of the operation of the spallation neutron source in December 1984.

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His research contributions in solid state physics cover a wide area using the techniques of neutron diffraction, neutron inelastic scattering and Mössbauer effect. His major contributions are in the field of lattice dynamics dealing with the dynamics of semiconductors and metals. Measurements on germanium, magnesium, zinc and many other crystals form a major contribution. In the area of magnetism, he has studied antiferromagnetic transitions in several alloys and studied the dynamics of magnetic spins by neutron scattering. Using Mössbauer effect, he has studied spin relaxation in ferrites. In addition to his own prominent contributions, he has also generated a strong group at Trombay which attracts international recognition. Iyengar's achievements in neutron scattering drew worldwide attention and his services were also sought in organizing neutron beam research in many countries of Asia. He has helped to initiate viable groups working on neutron beam research in the Philippines, Korea, Indonesia and Thailand.

While generating and sustaining such an excellent programme of basic research, Iyengar has always laid emphasis on applications in the field of nuclear energy. The result was that when R&D work on fast reactor systems became necessary, he was able to spearhead a task force which not only designed and built the zero energy fast reactor, PURNIMA, but provided the core of expertise for designing and putting together other fast critical systems, especially the one used for the Peaceful Nuclear Explosion experiment. PURNIMA has since been replaced by Purnima II, which is the first reactor to use U233. U233 is used as a nitrate solution with BeO as moderator and the parameters of this facility are presently being studied.

In nuclear physics, Iyengar not only gave overall direction to research in nuclear structure using the Van de Graaff accelerator, but encouraged spin-off applications like X-ray fluorescence and ion implantation. The insight gained by him in operating the Van de Graaff accelerator was used in directing the design and construction, wholly indigenously, of a 2 million-volt tandem accelerator. This type of machine will become increasingly popular in universities for heavy ion research and applications. He has also been guiding the setting up and utilization of VECC, Calcutta.

Iyengar has simultaneously overseen the development of other technologies as diverse as neutron radiography (of great potential importance in the examination of reactor fuels), high voltage technology for accelerators (which could be used in large energy storage systems) and lasers. Currently, his major interest is fusion and accelerator breeding.

At various stages of his career, Iyengar has been the Director of Physics Group, Chemical Group and Metallurgy Group of BARC with direct responsibilities of guiding research in these groups. With his instinct to identify the important, he initiated work in frontline fields like Mossbauer spectroscopy, Raman spectroscopy, low temperature physics, electron microscopy, materials research in magnetic and superconducting materials, NDT, sophisticated data acquisition and analysis systems and computer controlled instrumentation. Strong groups have now emerged in these fields in BARC under his guidance. Iyengar took over as Director, BARC, one of the most prestigious research organizations of the country, in March 1984.

Iyengar was elected Fellow of the Indian Academy of Sciences in 1966 and Fellow of the Indian National Science Academy in 1975. He was also honoured by the Roland Eotovos Physical Society, Hungary by electing him as Honorary Foreign Member. He received the Shanti Swarup Bhatnagar Award for Physical Sciences in 1971, Science and Technology Prize of the Kerala Government in 1978 and the FICCI Award for Physical Sciences in 1981. He was conferred the title "Padma Bhushan" by the President of India for his contributions to the Peaceful Nuclear Explosion experiment.

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S S Jha

The major research contributions in physics of Jha during the last 25 years can be classified broadly in terms of three main themes: (1) Properties of metals, semiconductors, insulators and plasmas in the presence of intense optical fields, (2) Use of laser Raman spectroscopy to investigate microscopic physical processes in condensed matter occurring at shorter and shorter timescales and confined to smaller and smaller spatial dimensions, and (3) New mechanisms for superconductivity in semi-metals and heterostructures. Apart from the importance of each of these studies from the technological point of view, the common motivation for all such investigations has been to understand and explain some of the many complex and fascinating phenomena in condensed matter, arising from a tremendous variety of combinations and recombinations of ions and electrons, and of atoms and molecules to form specific structures. In what follows, a brief review of these contributions is presented, along with some discussion of other work of importance.

Pre-Doctoral Work

Before starting his doctoral studies at the Stanford University, under the guidance of Prof. Felix Bloch, Jha had already written basic theoretical papers on neutron thermalization, nuclear magnetic resonance of three interacting spins, and a variational technique for obtaining propagating modes of a finite plasma. Out of these, the pioneering work[1] published in 1960 on the method of calculating energy distribution of thermal neutrons in a finite solid moderator assembly had the maximum impact, because it opened up a new approach to experimental as well as theoretical pulsed-neutron thermalization studies.

Nonlinear Optics

With the advent of lasers in the early sixties, the study of optical properties of matter again moved to the centre stage of activity, after a lapse of more than 30 years. Prof. Felix Bloch and Prof. Arthur Schawlow of the Stanford University encouraged Jha as a PhD student there to join the new revolution taking place in the old field of optics. Apart from high spatial and temporal coherence of a laser beam, it was immediately appreciated that optical electric fields in such a beam can approach the intra-atomic fields $E_a \cong 10^6$ to 10^7 esu. In other words, the optical nonlinearity of an electronic medium is no longer insignificant, a situation similar to that in acoustics. One has to completely revise his ideas for describing processes like optical polarization of a medium, light absorption, photoelectric effect, etc. Of

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course, the Raman nonlinearity due to the coupling of electronic and ionic motions and the consequent nonlinear optical response to an incident light was already demonstrated by Raman in 1928. However, the first theory and classification of purely electronic optical nonlinearities were presented by Armstrong, Bloembergen, Ducuing and Pershan (ABDP) in their famous paper [*Phys Rev*, **127** (1962) 1918] on the subject, only in 1962.

One of the basic assumptions made in the ABDP paper involved the use of the electric-dipole approximation (optical wavelength large compared to intra-atomic distances *a*), which immediately gives rise to the rule that any even-order nonlinearity in optical polarization is absent for a centro-symmetric medium. Jha, in his classic work in this field, realized that even free electrons can have second-order nonlinearity if one goes beyond the electric-dipole approximation, and showed that a more general theory[2] than that of ABDP leads to the second-harmonic generation even at a metal surface, plasmas and other centro-symmetric solids. This was experimentally verified immediately by Brown and Parks [*Phys Rev lett*, **16** (1966) 507]. The theory was later developed in greater detail by Jha and his collaborators[3].

In general, the basic problem of calculating nonlinear optical properties of insulators and semiconductors was attracting attention of many scientists during the late sixties. Jha and his group at TIFR, with an initial collaboration[4] with Prof. Nicolaas Bloembergen of Harvard University, showed that it is indeed possible to calculate these quantities from first principles. Actual calculations were carried out for semiconductors like Si, Ge, GaAs, InSb, InAs, etc. and for insulators like KDP and diamond. The first paper[4] on this is one of the most quoted works in the field.

Raman Spectroscopy

Electronic Raman Scattering: Highly tunable, pulsed and intense optical sources (lasers) also led to a renaissance in the well known field of Raman spectroscopy during the late sixties and seventies. With the development of highly sensitive optical multichannel detection techniques in the late seventies and early eighties, Raman spectroscopy can now be used to observe very weak signals (less than 10^{-2} photon-counts per second) arising because of either small Raman cross-sections (e.g. for the electronic Raman scattering process) or very small collection volume (e.g. for molecular monolayers at a surface) or very short observation times (e.g. less than 10^{-12} sec) dictated by the transient and nonequilibrium nature of the process under study. Apart from the study of the usual Raman scattering from ionic excitations (phonons), it became possible to observe and investigate purely collective electronic excitations like plasmons, magnons, etc. and single-particle electronic excitations of carriers in semiconductors. Jha developed a comprehensive and complete theory of light scattering from electronic excitations[5], applicable to any nonmagnetic solid, including semiconductors and metals. He showed that the correct interpretation of experimental results involving electronic excitations requires extension of the traditional theory beyond the electric-dipole approximation, and electron-electron interaction and screening are crucial in determining the efficiency of these processes. He demonstrated that the electronic Raman scattering, involving spin-flips for carriers in a single spherical valley or involving both spin-flips and charge density fluctuations for carriers in anisotropic multi-valleyed semiconductors directly determines the energy distribution of carriers.

Surface-enhanced Raman Scattering: The surface-enhanced Raman effect is the experimental observation that Raman cross-sections for excitations of many vibrational modes of certain molecules are enhanced by a factor 10^2-10^6 or more, when adsorbed or deposited on a metal like Ag. Similar enhancements of other nonlinear optical properties of molecules are seen when they are adsorbed on a metal surface. This enhancement indeed allows observation of a very small number of molecules confined to a narrow region (2-3 Å) at a solid surface, which is otherwise difficult if one uses conventional detection techniques. Surface Raman spectroscopy has thus become a very sensitive and nondestructive method of studying solid surfaces and adsorption of molecules on them, particularly with the use of powerful optical multi-channel analysers. Jha, in collaboration with two experimentalists (James Tsang and John Kirtley of IBM Research) and one theoretician (Girish Agarwal of Hyderabad University), presented a quantum theory of this surface-enhanced process[6] and established it[7] via controlled experiments with well characterized surface profiles for probing the physical processes involved. Jha's theory[8] contains both the short-range quantum enhancement due to electron tunnelling and charge-transfer processes (chemical-bonding effects) and the long-range classical electromagnetic enhancement due to resonant excitation of substrate surface-plasmon-polaritons. This theory is the only available complete theory at present, other than the "ad-atom" model of Otto. In collaboration with Agarwal, the theory has been extended to calculate other optical nonlinearities like second-harmonic generation, four-wave mixing, stimulated Raman cross-sections, etc. for adsorbed molecules.

Superconductivity

Electronic Mechanisms: To search for superconductivity of electrons in a solid at high enough temperatures, it is necessary to understand the basic existence condition for this unique phase transition. It is important to answer the question whether the effective attractive interaction of the well-known BCS theory, for carriers of opposite spins (i.e. time-reversed states) and momenta near the Fermi surface in a metal or a semi-metal can be provided by high frequency electronic excitations, rather than by the usual lattice-phonons which are believed to be responsible for superconductivity in known materials. Ginzburg (1970) in USSR and Bardeen (1973) in USA had suggested that one might get very high temperature superconductivity in a metal-semiconductor sandwitch structure in which the electrons in the metal can exchange well-defined electronic excitons in the semiconductor by tunnelling back and forth. In order to examine this possiblity, Jha[9,10], with his students, S Rangarajan and S Srinivasan, made detailed calculations of the interface exciton modes and of the resulting effective BCS interaction in the metal to show that the exciton mechanism by itself may not lead to superconductivity in such structures, but it can enhance T_c due to the usual phonon mechanism by about 30% (for a plane interface) to 60% (for a spherical interface) when the thickness of the metal film or the radius of metal granules is reduced to about 20 Å.

Jha[11], in collaboration with P Bhattacharyya and S Srinivasan, investigated yet another system involving pressure-induced phase transition from an insulating phase of a small band-gap insulator to a semi-metal which may become a superconductor at lower temperatures. They showed that when the ratio of the hole-mass, m_h, to the electronmass, m_e, is much different than 1, an additional well-defined sound-like electronic mode (called acoustic plasmon mode) exists in the system. Such a mode has indeed been observed in photo-excited carriers in GaAs, recently. For $m_h/m_e >$ 10, and carrier concentrations, n_c, greater than 10^{19} cm^{-3}, they showed that exchange of such acoustic-plasmons may indeed give rise to superconductivity at high enough temperatures. They argued that this mechanism is already operative partially in the semi-metal bismuth, although because of the low m_h/m_e ratio (~ 5) and much lower n_c, it only aids slightly the superconducting transition in this material due to the usual phonon mechanism.

In recent years, the study of interplay between magnetism and superconductivity in the same material has been of considerable interest. Jha[12] and his student, Ranjan Chaudhury, have studied this problem from a slightly different point of view, and have obtained an explicit expression for the superconducting transition temperature, T_c, for the conduction electrons in a paramagnetic metal when the paramagnetic system is close to magnetic ordering, without necessarily considering the phonon-exchange mechanism. As earlier noted by Uspenskii (1979), for a paramagnetic system, just before the onset of magnetic-ordering transition, the magnetic susceptibility is enhanced considerably giving rise to the possibility of changing the sign of the effective electron-electron interaction. Such an electronic mechanism may be playing a role in a recent experimental observation of such a transition in Y_9Co_7.

Some Other Work and Future Plans

In a short write-up like this, it is difficult even to enumerate other significant work done by Jha and his collaborators, with more than 100 research publications to his credit. However, one must mention at least some of them which contained extremely interesting and novel ideas. His work on the possibility of fabricating a soft X-ray laser[13] by short-pulse-laser heating of solid targets like Fe, and the subsequent fast production of highly ionized lasing plasma; the monograph[14] written in collaboration with his student Satish Srivastava, on the generation of laser-induced parametric instabilities in a plasma; the work on spherical implosion and laser-induced thermonuclear fusion; a mathematical theory of solitary waves (solitons) in 3-wave parametric interactions[15]; a new method of calculating microscopic screening of ion-ion interaction and phonon-dispersion in semiconductors, presented in collaboration with his student, Karanjeet Arya; *ab-initio* calculations of quantum defect parameters for highly excited Rydberg states of atoms; and the work on calculating phonon and polariton modes in a superlattice are a few of such examples.

In future, it is proposed to continue to solve new problems and ask as well as answer new questions raised by more and more sophisticated and sensitive experiments in optics and condensed matter physics. For example, one knows that Raman spectroscopy, with pico-second and femto-second incident laser pulses, is being used since last year to directly observe dynamical processes (both electronic and ionic) in highly excited non-equilibrium carriers in semiconductors, in the time-regime of 10^{-12} seconds or less. This is revolutionizing a very important, futuristic, branch of semiconductor physics, and Jha has taken up this problem recently to reformulate the theory of Raman scattering for this non-equilibrium and transient case, so that proper interpretation of existing experiments can be made, and new important experiments can be performed to probe the nonequilibrium dynamics of the carriers.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S K Joshi

Joshi's contributions span over a wide variety of topics in solid state theory and in atomic and molecular collisions. His early researches were concerned mainly with study of phonons in metals and insulators. A new model for incorporating the role of electrons in determining the lattice vibrational frequencies in normal metals was proposed[1]. A microscopic theory for phonons in transition and noble metals was also proposed[2]. This is based on calculating the dielectric screening function for such metals using a model of noninteracting s and d-bands. This model has proved successful when applied to various transition and noble metals. A generalized theory for dielectric screening in metals has also been given[3].

Later, Joshi did research work in areas of electronic states in disordered systems and theory of electron correlation in narrow band solids. A number of methods were proposed for the study of electrons in disordered systems[4-7]. These models have been applied to a number of binary alloy systems to explain the observed optical and photoemission measurements. These approaches have also been used to study transport properties like electrical conductivity and Hall effect in disordered alloys. The usual single-site approximation commonly used for the study of electrons in disordered alloys has been generalized by proposing a cluster approximation wherein correlated scattering from various sites of the lattice is incorporated[8].

Useful contributions have also been made to the problem of electron correlation in narrow energy bands possessed by the transition and rare earth metals, their compounds and alloys. The s-d interaction which is quite important in such metals, has been added to the Hubbard Hamiltonian for such systems[9]. The Hubbard Hamiltonian has also been generalized by including interatomic Coulomb interactions[10].The instability of paramagnetic state against the ferromagnetic and antiferromagnetic states has been studied in the presence of these added interactions. The role of these interactions *vis-à-vis* metal-nonmetal transition has also been investigated.

Joshi has also conducted studies on excitation and ionization processes in atoms, ions and molecules due to the impact of electrons and protons[11-12].

The current research interests of Joshi lie in the study of surface states[13], surface segregation[14], and transport properties of spin glasses[15].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S S Kapoor

Kapoor has made pioneering contributions to several studies in the areas of nuclear fission process, excitation energy dependence of nuclear shell effects and heavy ion physics. Starting his research career under the guidance of Dr R Ramanna in 1960, he carried out experimental studies on the emission of prompt neutrons and gamma rays in thermal neutron induced fission of ^{235}U using neutron beam from APSARA reactor, and obtained experimental evidence for significant angular momentum in the fragments produced by the dynamics of the scission act. Another important outcome of these studies was the determination of the emission spectrum of the neutrons through the analysis of the laboratory-neutron spectra measured at specified angles with the direction of motion of the fragments. Subsequently, during 1964-66, he worked at the Lawrence Berkeley laboratory in USA with Dr S G Thompson and carried out the first physical measurement of Charge division in fission through K X-ray measurements and also obtained evidence for a new region of nuclear deformation through K X-ray yield measurements. At Berkeley, he also took a leading part in studies on fragment angular distributions in the alpha-particle induced fission carried out with the Berkeley Cyclotron, which for the first time enabled determination of the saddle point K-distributions up to very high excitation energies.

On return from USA, Kapoor set up indigenously a high resolution cooled Si(Li) detector system at a time when these systems were in the early stages of development and not available commercially. With these detector systems, a series of more detailed studies on K X-ray emission in fission were undertaken in thermal neutron fission of ^{235}U and spontaneous fission of ^{252}Cf. Realizing the potential of high resolution Si(Li) detector system in performing for the first time energy dispersive X-ray fluorescence analysis of materials, he also played a leading role in the setting up of X-ray fluorescence facilities at Trombay and also elsewhere in the country.

Kapoor's recent experimental research work has been concentrated on studies of the light charged particles occasionally emitted in fission, which provide information on the static and dynamic state of the scission configuration and indirectly on the nature of large scale motion of nuclear matter from saddle to scission in the fission process. For some of these experiments involving low probability events, new experimental techniques were developed which allowed electronic measurements of angles simultaneously with large solid angles of detection. Consequently, experimental

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data covering a number of correlations among the parameters of interest in light charged particle accompanied fission could be obtained with the neutron fluxes available at CIRUS reactor in an area of research which otherwise fell within the reach of only very high flux reactors. These experimental studies, which included multiparameter recording and computer analysis of the data, are among the most complicated and sophisticated experiments carried out internationally in the field of nuclear physics. With several years of experimental work, results on a number of correlations in light charged particle emission in fission were obtained for the first time; these have provided important information pertaining to nuclear viscosity in the motion of fissioning nucleus from saddle to scission.

More recently, Kapoor adopted a novel experimental technique based on back-to-back ΔE-E telescope arrangement to measure not only the fission fragment masses but also their energy losses in gases which enabled a thorough study of the mechanism of energy loss of the heavy ions. This measurement technique also allowed for the first time simultaneous measurements of the fragment mass and charge distributions and their correlations with the fragment kinetic energy. These studies have provided new information on the fission process, particularly on the aspects of similarity of this process with the heavy-ion deep inelastic collisions.

Kapoor and coworkers have also made important contributions on theoretical aspects of nuclear behaviour and fission phenomenon, particularly on the subject of nuclear shell corrections and level densities. A proper understanding of the shell corrections in nuclei has emerged only during the last 15 years or so, resulting in the important discoveries of double-humped fission barrier, shape-isomers and the prediction of the possible existence of an island of supertheavy nuclei. Kapoor and coworkers have been contributing to these developments and did pioneering work on the washing out of shell effects with excitation energy, which has a bearing on the production possibility of superheavy nuclei by heavy ion reactions. These studies have also yielded an alternative temperature smearing procedure for the evaluation of shell correction energies.

During the last few years, Kapoor has made important original contributions in the newly emerging areas of heavy-ion physics. In these studies, he formulated new theoretical approaches to the calculations of heavy-ion fusion cross-sections from fragment angular distribution data and also purely on the basis of heavy-ion trajectory calculations, including the role of both radial and tangential friction terms and nuclear-nuclear potentials. Important contributions were recently made by him on the question of connection between nucleon exchange process and energy dissipation by a proper consideration of correlated particle transfer in heavy-ion deep inelastic collision. Recently, he and his coworker, V S Ramamurthy, have worked out a new model to explain fission-fragment angular distributions in heavy-ion fusion reactions.

During 1980-81, at the invitation of Prof. H J Specht, Kapoor worked for a year at the University of Heidelberg and conducted experiments to investigate phenomena associated with deep inelastic collisions in medium mass target nuclei with energetic krypton and xenon heavy ion beams from the Darmstadt heavy ion accelerator facility. These studies showed an unexpected final three-body state with strong proximity effects, establishing a new type of splitting process proceeding on a fast time scale.

Over the years, Kapoor has developed a strong research group at Trombay in the areas of nuclear fission and heavy ion physics. He is at present Head, Nuclear Physics Division of BARC and is also Project Director of the Medium Energy Heavy Ion Accelerator Project. Under this project, a 14 MV tandem Van de Graaff Pelletron accelerator facility is being set up at the Tata Institute of Fundamental Research (TIFR) for nuclear physics research with energetic heavy ion beams. The second phase of this project envisages development, construction and installation of a superconducting linear accelerator to further boost the energy of the heavy ions from the Pelletron accelerator. Kapoor and his team of scientists from BARC and TIFR are currently working on the various aspects of the project involving both the setting up of this heavy ion accelerator facility and building of the necessary instrumentation for the utilization of the heavy ion beam for nuclear physics experiments.

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P K Kaw

Plasmas are inherently nonlinear in nature. They are typically generated in a state which is far from thermodynamic equilibrium and therefore have enormous reservoirs of free energy. The plasma then attempts an approach to equilibrium by driving up large amplitude collective waves/oscillations at the expense of these free energy sources. The large amplitude waves finally take the plasma into a coherent or turbulent nonlinear state which we encounter in the experiments. My work has largely been devoted to an elucidation of linear and nonlinear collective phenomena in plasmas with special emphasis on application to thermonuclear fusion ionospheric irregularities, etc.

My early work (1964-67) was on nonlinear wave propagation effects in weakly ionized plasmas and semiconductors. The nonlinearity arises primarily from collisional effects, effects due to band nonparabolicity, etc. and becomes important when intense electromagnetic waves are injected into the ionosphere, semiconductors, etc. Interesting phenomena like harmonic generation, mixing, crossmodulation and demodulation, etc. were studied in these investigations.

From 1967 to 1971, I worked at the Princeton University, USA and directed my attention to nonlinear problems connected with laser-plasma interactions[1-4]. As is well known, laser-induced fusion depends on absorption of intense laser radiation by a thin hot plasma layer which is formed when a solid pellet is zapped by the laser beams. Collisional absorption in such hot plasma layers is negligible. In my work, I was able to demonstrate the importance of a number of nonlinear and anomalous processes in laser plasma interactions. Notable among these works are (a) laser induced parametric instabilities which lead to anomalously large absorption as well as back scattering and side scattering[1,4], (b) filamentation of laser light due to ponderomotive force[3], and (c) relativistic nonlinear effects which have also found application in pulsar radiation phenomena[2]. Most of the results of these investigations have received experimental confirmations.

In 1971, I returned to India and joined the Physical Research Laboratory (PRL). Here, I continued work on the general development of the theory of parametric instabilities with new applications to radio frequency wave interaction with magnetically confined plasmas[5-7]. This work has found application in RF-plasma heating and RF excitation, suppression and control of various waves in magnetically confined plasmas. It has also been used to interpret some very interesting ionospheric heating experi-

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ments carried out by a transmitter in the USA[8]. At PRL, I also got exposed to a new set of problems connected with observations of density irregularities in the E and F regions of the ionosphere. These irregularities are generated by plasma instabilities driven by cross-field currents and cross-field density gradients. I have carried out a number of investigations on the linear and nonlinear theories of ionospheric irregularities primarily with an effort to understand the discrepancy between the observations and theoretical models[9,10].

In 1975, I returned to Princeton and started work on the theory of magnetically confined plasmas. Here, I have concentrated on basic physics problems of relevance to stability, transport, heating and current drive in Tokamak-like confinement systems[11-14]. It was demonstrated that some decade old conventional wisdom on the stability of drift waves in sheared geometry in collisional and collisionless plasmas was actually incorrect[11]. Drift waves are driven unstable by the expansion free energy of the plasma and are widely believed to be responsible for turbulent transport observed in Tokamaks. A number of calculations on tearing modes and magnetic reconnections in magnetically confined plasmas were also carried out in this sphere[12,13]. Magnetic reconnection is a process by which stored magnetic energy in a high conductivity plasma can be released very rapidly often with disastrous consequences for hot plasma confinement. A model calculation demonstrating the initiation of a magnetic reconnection process was carried out[12]. This work has been verified by detailed numerical simulations by groups in USA and Germany and has recently been applied by Eugene Parker to a new set of models for solar flares. During this period, I also carried out a number of investigations on novel methods for deriving steady currents in a Tokamak. This is an important current area of research, since steady state performance is considered crucial to the concept of a Tokamak reactor. A novel passive approach to Tokamak current drive in reactor grade plasmas was described[14], which depends on the synchrotron radiation emitted by such plasmas naturally.

In 1982, I returned to India and assumed Directorship of the Plasma Physics Progrmme at PRL, Ahmedabad. In the last three years, we have designed an indigenous, low field, moderate sized Tokamak, which is currently under fabrication and should be ready for assembly by the Spring of 1986. We have also initiated a number of basic plasma physics experiments on nonlinear waves and turbulence in plasmas, compact torus generation by relativistic electron beam, RF-plasma interactions in toroidal plasma assemblies and so on. I have also continued to carry out theoretical investigations on resistive tearing and ballooning modes in high temperature plasmas with and without the presence of electron beams, relaxation phenomena in Tokamak plasmas, current drive in Rotamaks, etc.[15].

During the next few years, we hope to carry out intense experimentation on the Tokamak ADITYA and to investigate a number of phenomena related to control of plasma disruption by feedback coils, heating of plasmas by radio-frequency waves in the Alfven range of frequencies, study of the confinement/stability properties of plasmas with currents in energetic electron beam, etc. We also hope to continue experiments on small plasma devices and concentrate on the physics of nonlinear phenomena, origin of chaos and turbulence, trapped particle effects, magnetic reconnection and field generation by dynamo effect, etc. We shall also expend a great deal of effort in evolving a programme in which theoretical work and experiments proceed hand in hand.

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15. Sundaram A K, Sen A & Kaw P K, Stabilization of resistive ballooning modes in high temperature plasmas, *Phys Rev Lett*, **52** (1984) 1617.

L S Kothari

Kothari's early research work was mainly in the field of quantum electrodynamics. He later worked in the areas of (i) neutron physics, (ii) lattice dynamics, and (iii) solar cells.

It was shown that Riesz potentials could be used to eliminate the basic divergences in quantum electrodynamics and meson physics. Dyson pointed out that this method was equivalent to the method of distributions. Fermi's theory of pion production in nucleon-nucleon collisions was extended to include heavy mesons and applied to explain the then available experimental results.

(i) Extensive work has been done in the area of neutron scattering from solids, neutron thermalization and diffusion. A neat and straightforward method for calculating neutron scattering cross-section from solids using second quantization techniques was developed[1]. It was observed by many workers that the measured cold neutron cross-section for graphite did not agree with the calculated values. For the first time, a theory on neutron scattering from anisotropic solids was developed and the discrepancy between measured and calculated cross-sections for graphite was removed[2].

Pulsed neutron experiments are used widely to determine the value of the diffusion coefficient of neutrons in different moderators. At one time there was a major discrepancy between theory and experiment, as highlighted by Prof. N Corngold of California Institute of Technology (Pasadena, Calif., USA): 'If the experimental points are correct, they stand in direct contradiction to rather direct consequences of the Boltzmann equation......'. This major discrepancy was resolved by introducing the concept of Bounded Boltzmann equation[3]. Following this, lot of work has been done on this by many workers both here and abroad. It has been reviewed in detail by Cokinos [Cokinos D, *Advances in nuclear science and technology*, Vol. 2, edited by Greebler and Henley (Academic Press, New York) 1966]. This work brought out the necessity of measuring time dependent neutron spectra in moderators. It was shown that these spectra would differ markedly from Maxwellian and would be peaked in certain energy regions and depleted in others. In a number of laboratories in USA, USSR, Japan and Australia, these measurements have been carried out.

The problem of diffusion of neutrons inside small assemblies is becoming very important. By introducing the concept of energy dependent buckling, it was possible for the first time to explain many of the fine details in the experimental results[4]. Using the same concept, the problem of 'neutron wave' propagation was investigated in detail in different moderators[5]. Regarding this work, Prof. N

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N Hanna of Manchester University (UK) wrote: 'Comparing our experimental ($\alpha^2 - \zeta^2$) νs ω^2 curves with various theoretical predictions, it seems that calculations using energy dependent boundary conditions are the best theoretical results published so far'.

Extensive work has been done on the thermalization and diffusion of neutrons in two of the most important moderators, water and heavy water[6]. A new scattering was developed, about which Prof. H Amster of University of California, Berkeley, USA wrote: 'The potential practical benefits are great now not only because the improvements over the simpler models are more pronounced, but also because it is easier to incorporate intricate new procedures into the program.' The long outstanding puzzle that in the steady state the neutron temperature does not fall below about 21 K even when H_2O ice is maintained at liquid helium temperatures was resolved. Neutron thermalization in ice (H_2O, D_2O and mixtures) has been studied down to liquid hydrogen temperatures and the usefulness of these as cold neutron sources has been investigated[7].

The study of the effect of anisotropy in neutron scattering on their thermalization and diffusion is a difficult problem and only recently some work has been done on this problem. We have successfully explained neutron spectra measured along different angular directions coming out from beryllium and beryllium oxide slabs[8]. This work has been picked up by many other groups.

The simple 'two-group' method[9] and a variational technique[10] have been developed for obtaining solutions for the Boltzmann equation, which give results that could be obtained earlier only by very extensive multigroup calculations.

Work is also being done on the theory of control rods under complex geometries and on fast multiplying[11] and non-multiplying[12] systems.

Most of this work has been referred to extensively in textbooks on solid state physics as well as on reactor physics, research papers and reports.

(ii) Using the 'unfolding technique' developed in reactor physics, a method for finding the frequency distribution function for anisotropic solids has been developed[13]. Here, one uses the measured specific heat data to determine this function and lot of interest has been shown in it by workers in this field. The anharmonic vibrations of a small linear chain have also been investigated and some interesting results obtained. A model for frequency distribution function of glass has been suggested[14].

(iii) Work has been done on transients and partially illuminated solar cells. A theory of the performance of vertical junction solar cells has been given. Shockley and Read, and Hall theory of recombination of electrons and holes at traps has been extended to allow for finite relaxation time at traps[15]. To explain the behaviour of solar cells at ultra-high light intensities, the possibility of plasma reflections has been suggested[16].

Four books have been published by Kothari: (i) *Introduction to Lattice Dynamics* (with A K Ghatak) (Addison-Wesley, New York, 1972); (ii) *Basic Physical and Chemical Data* (with C N R Rao) (East-West Press, New Delhi, 1970); (iii) गणित मनोरंजन (with O P Sharma) (NCERT, New Delhi); and (iv) कागज और धागों के खेल (शकुन प्रकाशन, दिल्ली).

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P Krishna

(1) Mechanism of the Growth of Polytype Structures

Krishna determined the crystal structures of several long-period polytypes and examined the mechanism of their growth in the light of the existing theories of their formation[1-4]. His experimental results have shown that the structure of most long-period polytypes cannot be understood in terms of Frank's theory of spiral growth around a giant screw dislocation in a perfect basic matrix.

He has successfully explained[5-7] the formation of such anomalous polytype structures in terms of the "The faulted matrix model of polytypism" which, for the first time, considered the influence of low-energy stacking faults in the parent matrix from which the polytype structures originate. This model has been very successful in predicting the most-probable structures in different materials like silicon carbide, cadmium iodide, lead iodide and mica. Krishna and coworkers have been able to explain the origin of rhombohedral structures and the different structure series observed in various materials.

(2) Phase Transformations in Close-Packed Structures

Krishna has applied X-ray diffraction methods to study the mechanism of phase transformations in close-packed structures[8,9]. He has examined crystals quenched during the process of transformation and shown that the diffuse intensities produced on X-ray diffraction photographs in the disordered intermediate state can be explained in terms of a non-random distribution of stacking faults.

Krishna and coworkers[10-13] have modified the theory of X-ray scattering from randomly faulted close-packed structures to predict the diffraction effects produced by different types of non-random fault distributions. By comparing the calculated diffuse intensity distribution in reciprocal space with that recorded on a single-crystal X-ray diffractometer, they have successfully determined the type of faults involved and the mechanism of the transformation in SiC and ZnS.

This is the first time that X-ray diffraction methods have been successfully used to actually determine the mechanisms of a structural transformation by studying the diffuse X-ray scattering from a disordered crystal obtained as an intermediate state during the transformation from one ordered state to another.

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(3) Origin of Giant Screw Dislocations in Platelet Crystals

The origin of highly energetic, metastable screw dislocations with giant Burgers vectors of the order of several hundred Angstroms, which are believed to give rise to macro-spirals on crystal surfaces, has been a puzzling enigma for crystallographers and solid-state physicists for a long time. Recently, Krishna and coworkers[14] developed a zero-order theory to explain the origin of giant screw dislocations due to hoop stresses created in a platelet crystal growing laterally with an impurity gradient. Frank's theoretical prediction that screw dislocations of such large Burgers vectors should have a hollow core has been spectacularly verified[15] by Krishna by recording the core of such dislocations on X-ray topographs taken from an SiC crystal displaying three macro-spirals on its surface.

Krishna's researches have resulted in the publication of over 60 research papers, 6 review articles and two books. His book on "Polymorphism and Polytypism in Crystals" written in collaboration with Dr A R Verma has become a standard work of reference in this field. It has been translated into Russian by the USSR Academy of Sciences under their "Series on Earth Sciences—Fundamental Works and Treatises of Foreign Scientists". More recently, Krishna has edited a special volume on "Crystal Growth and Characterization of Polytype Structures"[16].

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R S Krishnan

(A) Colloid Optics and Light Scattering

During the five years from 1933 to 1938, Krishnan carried out a long series of investigations in the field of colloid optics and light scattering and published 25 papers. The most important contribution made during this period was the discovery of a new optical effect in light scattering now referred to by several authors as the "Krishnan Effect", the discovery of the presence of large molecular clusters in liquid mixtures[1], glasses[2] and colloidal solutions. He also enunciated a general relation called "Reciprocity theorem in colloid optics", which connects the three depolarization ratios, ρ_u, ρ_v and ρ_h, defining the scattered light in unpolarized, vertically polarized and horizontally polarized incident light respectively[3]. Krishnan was the first to show that the depolarization (ρ_h) of the light transversely scattered by any scattering medium when the incident light is polarized with electric vector horizontal gave directly an insight into the size of the scattering particles, while the depolarization factor (ρ_v) when the incident light is polarized with electric vector vertical is intimately connected with the shape or optical anisotropy of the scattering centres. $\rho_h = 1$ indicates that the scattering particles are of molecular dimension, while a vanishingly small value of ρ_v indicates that the particles are spherical and isotropic. Krishnan developed a delicate technique using plane polarized light for the study of the characteristics of the scattered light. He discovered a correlation between the dispersion of depolarization of the scattered light on the one hand and light absorption, magnetic electric and flow birefringence of a large number of colloidal systems on the other.

Prof. R Gans, in one of his papers [*Phys Z*, **37** (1936), 19] christened Krishnan's discovery as "Krishnan Effect", which enabled the existence of molecular clusters in a homogeneous medium to be visibly demonstrated. As pointed out by Prof. Hans Mueller of MIT (USA) [*Proc R Soc*, **A166** (1938) 425] and by Prof. J Perrin [*J chem Phys*, **10** (1942), 415], it is now clearly recognized that the reciprocity relation in light scattering (which is known as "Krishnan Effect") formulated and established by Krishnan is of fundamental importance in optics and is of the widest generality. The importance of Krishnan's work in colloid optics can be judged from the fact that he was requested by Prof. Wo Ostwald, the Editor of *Kolloid Zeitschrift*, to contribute two detailed articles on colloid optics and molecular clustering to that journal[4].

(B) Nuclear Physics

As an 1851 Exhibition Overseas Scholar

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from October 1938 to 1941, Krishnan carried out some important studies in the Cavendish Laboratory using the Cambridge cyclotron in newest fields of research in nuclear physics, including nuclear fission. Numerous papers by Krishnan on deuteron bombardment of the heavy elements were published by the Royal Society, Cambridge and Philosophical Society and in *Nature*. These investigations have led to a better understanding of the mechanism of deuteron-induced disintegrations. The most important contribution to the subject was the discovery of the deuteron induced fission in uranium and thorium[5] and also the occurrence of deuteron-tritium reaction in some elements[6]. The second reaction is important, as it provided a method of preparing tritium, the isotope of hydrogen with mass 3. One of his important research papers[7] was voluntarily withheld from publication in 1941 for the duration of the war. This isotope is very important, as its production is the first stage in the production of the important nuclear fuel, plutonium.

Krishnan's work in nuclear physics at Cambridge elicited the highest praise from the leading authorities in the field. Sir John Cockcroft, F.R.S., N.L., who was the head of the Harwell nuclear research establishment in England, wrote as follows concerning Krishnan's work at the Cavendish Laboratory: "Dr Krishnan worked at Cambridge under my supervision for three years; during two years of this period he was in complete charge of the running of and the work carried out on the Cambridge cyclotron. The fact that he was able to do this when the more senior staff were withdrawn at the outbreak of the war is a very strong recommendation for Dr Krishnan as an experimental physicist. Dr Krishnan has shown originality and good judgement in selecting the subjects for his research, and in my opinion, is the best experimental physicist from India who has worked in the Cavendish Laboratory during my residence there, that is over a period of fifteen years."

The Secretary to the Royal Commission for the Exhibition of 1851, London, wrote as follows to Krishnan after his return to India: "Your work at the Cavendish Laboratory, where you made several notable contributions to nuclear physics, has received high praise from the Commissioner's Examiner, and on that account alone, I am able to offer you the congratulations of the Commissioners on a very successful tenure of their scholarship."

(C) Crystal Physics, Raman Spectra and Brillouin Scattering

From July 1942 onwards, Krishnan carried out investigations in crystal physics using physical methods including especially the diffraction of X-rays and the spectroscopy of the Raman effect and made important contributions to the physics of the solid state. He successfully developed the Rasetti technique of excitation for Raman effect for the study of the Raman spectra of crystals. Using this technique, he obtained for the first time the second order Raman spectra of diamond, alkali halides, quartz, gypsum, calcite, etc. His results with diamond[8], rock salt[9] and ammonium chloride[10] afforded a direct experimental verification of Born's dynamical theory of crystal lattices, viz. the vibration spectrum of any crystal consists of a continuum and in the first order Raman spectra one obtains only those phonons for which the wave vector *k* is zero, while the second order Raman spectra consist of a continuum with certain number of prominent peaks corresponding to the octaves and combinations of van Hove singularities in the phonon dispersion curves. These experimental observations of Krishnan opened up a vast new field of theoretical research in lattice dynamics of various crystals and this has ultimately led to a better understanding of the solid state of matter. With the aid of the new and powerful ultraviolet technique for the study of the Raman spectra of crystals developed by Krishnan with self-made tools, several hitherto unrecorded features of the Raman spectra of many crystals, including those which exhibit phase transitions, have been reported by Krishnan and his associates from the Indian Institute of Science, Bangalore. Immediately after Krishnan's results on diamond and alkali halides were published, similar investigations were carried out in England, Russia and Canada using Krishnan's technique.

The Doppler shifts of frequency due to the scattering of light by thermal waves, commonly known as the Brillouin scattering, were recorded by Krishnan for the first time in diamond[11], alumina or corundum fused silica[12] and in alkali halides using the Rasetti technique. The most important achievement from this study is the recording of Brillouin spectra using an ordinary spectrograph without interferometric aid. Along with his student, V Chandrasekharan, he developed a new theory of Brillouin scattering in birefringent crystals[13]. In a most general case, one should observe 12 pairs of Brillouin components. All these investigations were extensively quoted in the book on optics by Prof. A Kastler of Paris.

Krishnan had developed a new method of measuring with precision the coefficient of expansion of crystals. He applied this technique for the case of diamond and obtained for the first time the thermal expansion coefficient of diamond above the room temperature and established the failure of the well known Gruneisen law[14].

Krishnan initiated work on the determination of the geological time of Indian rock formations[15]. Along with his student, Venkatasubramanian, he obtained some very important results on the ages of the Deccan traps.

Krishnan has also made some valuable contributions in crystal elasticity, crystal photoelasticity and ultrasonics.

During the past five years, Krishnan has prepared the complete bibliography of more than 40,000 papers published on Raman effect since its discovery in 1928 up to the end of 1984. Index cards have been prepared for all the papers giving details of the author(s), title, the journal reference, brief abstract and keywords.

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D Lal

The primary thrust of Lal's work lies in the fields of nuclear physics, earth sciences and solar system physics. In his early career, under the guidance of Prof. B Peters, he studied the composition of the primary beam of the cosmic radiation, and the nuclear interactions of high energy nucleons, with special reference to the production of elementary particles and spallation products. His achievements include the discovery of associated production of K-mesons, and the discovery of existence of the negative K-meson. During 1955-70, he concentrated on studies on cosmic ray spallation produced naturally as tracers in earth sciences. His work, in collaboration with other scientists in India and abroad, led to the detection of about 10 cosmic ray produced radionuclides and their applications. He also established the National Radiocarbon Laboratory, and the first laboratory in India for nuclear studies in hydrology; these were both set up at the Tata Institute of Fundamental Research, Bombay.

During the sixties, he concentrated on studies on nuclear effects, "spallation products" and "tracks", in meteorites, and successfully used the observed effects, largely investigated by him and his colleagues, to deduce (1) temporal variations in the intensity of cosmic radiation in the last few million years, (2) the evolutionary history of meteorites, and (3) geophysical and geochemical processes using radionuclides as tracers.

He has successfully applied the cosmic ray nuclides for the study of basic processes in the atmosphere and the hydrosphere. He recently showed the importance of studies on small particles (micron range) suspended in the oceans in regulating the ocean chemistry, including the marine food-chain. The work involved the use of sophisticated techniques to collect the micron size particles, and tagging their movement using a variety of natural and artificial radionuclides.

Lal's investigations on meteorites won him recognition as Principal Investigator for the study of lunar samples; he has studied samples from all the American and Russian lunar missions. These and other investigations carried out by him, based on cosmogenic tracks and isotopes, during 1970-1980, proved very valuable for studying: (1) paleontology of solar cosmic ray particles accelerated during flares, and (2) evolutionary history of the lunar regolith and genetic interrelationships between lunar rocks and meteorites.

An interesting recent contribution by Lal is a quantitative model for the annealing of charged particle tracks in common rock forming minerals. This now makes it possible to (i) make quantitative

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corrections of terrestrial fission track ages due to annealing, and (ii) determine the cooling rates of certain meteorite parent bodies.

During the last five years, Lal has worked extensively on the terrestrial distribution of natural radio carbon and has determined the implications of the radiocarbon paleodata for (1) temporal variations in solar activity, (2) secular variations in the geomagnetic dipole field, and (3) secular variations in the carbon cycle during the past $(40 \cong 50) \times 10^3$ years.

The above investigations revealed that whereas the so-called "Suess Wiggles" in $^{14}C/^{12}C$ ratios, as recorded by tree rings, could be due to solar modulations of cosmic-ray flux, the slow variation in $^{14}C/^{12}C$ ratios was probably not of geomagnetic origin. This challenges the present concensus that the earth's dipole field changed by about 50% during the Holocene.

This result led him to develop the *in situ* cosmic ray production of isotopes in rocks and trees to measure changes in the geomagnetic field, and also to study a variety of geophysical processes, e.g. rock denudation rates. The field of *in situ* cosmic ray produced isotopes largely as a result of the work carried out by him recently in collaboration with J. R. Arnold and K. Nishizumi has now become a field in its own right. It is now possible to study quantitatively rock erosion rates, basing on the *in situ* cosmic ray produced radioisotopes ^{10}Be, ^{26}Al, etc. To date, continental denudation rates have been based primarily on estimates of transport of detrital sediments and dissolved elements to oceans from continental run-off.

Lal has to his credit more than 200 scientific publications. He is a fellow of several scientific academies. He was elected Foreign Associate of the National Academy of Sciences, USA in 1975 and Fellow of the Royal Society, England in 1979. He has served as Vice-President and Foreign Secretary of the two Indian Science Academies. He was elected President of the International Union of Geology and Geophysics at the 1983 Hamburg General Assembly.

Lal worked at the Tata Institute of Fundamental Research (TIFR) during 1949-1972. The last position held by him at TIFR was that of a Senior Professor. He then moved over to the Physical Research Laboratory (PRL), Ahmedabad as Director and served in this position until 1983. This institute has served as the cradle of the space research programme in India, and has now embarked on active programmes in the fields of infrared astrophysics, experimental plasma physics and climatological studies. He continues to be with PRL as a Senior Professor, and also holds a joint appointment with the Scripps Institution of Oceanography, La Jolla since 1967. He has been visiting the Scripps Institution regularly since then, teaching and carrying out research in the fields of oceanography, atmospheric sciences, hydrology, meteoritics and evolution of the solar system.

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B S Madhavarao

My research work falls into two streams: (i) critical work; and (ii) original work.

Critical Work

(1) The German Nobel Laureate, J Stark, had published a paper in 1938 in which he had proposed a theory of ring-structure of the electron. While working with Prof. Max Born, who was in Bangalore for six months during 1938, I had developed on the basis of Born's non-linear field theory, the possibility of a ring structure for the electron. This work was done before Stark's work on the same subject. On looking at his work, I noticed some serious errors consequent on the fact that he had not used the principles of the theory of relativity, since he did not believe in it. My criticism and Stark's reply to the same were published in *Phys Z* (1939). My final strongly worded reply to his observations was published in the same journal. Thereafter, he took no further part in the controversy.

(2) Raman and Nagendranath had published in the *Proc Indian Acad Sci* (1938) a paper in which they claimed that many properties of light could be explained on the basis of a neutrino theory. In a later issue of the same journal, I published a paper showing the inadequacy of the neutrino theory of light, and Raman was gracious enough to accept the correctness of my criticism.

Original Work

(1) My work on Born's non-linear field theory done in 1938 was referred to as 'Madhavarao's theory of action functions' in the Poincaré Institute Memoirs of 1938. In a letter written to me, Prof. Pauli explained how some of the points I had raised about Born's non-linear field theory could be explained satisfactorily.

(2) Papers on Newtonian classical mechanics relating to the Lagrangian and Hamiltonian formulations were published during 1932-35. One of these papers on "Separable systems in classical and wave mechanics" published in *Math Annalen* in 1935 has been referred to in several books on mechanics published in Germany.

(3) In my work done in 1937, I used elliptic function formulae for the study of plane cubic curves, and in particular a special type of cubic curve studied by Newton. My theorem has been referred to as "Madhavarao's theorem on apolar cubics" in an article published by *Acad Lincei*, Rome (1937).

(4) The most important part of my research work was done during 1942-47. This work related to the application of the theory of groups and group representations in modern theoretical physics, specially in the theory of elementary particles. I was possibly the first one in

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India to undertake work of this type. I set up order relativistic wave equations of the Dirac type for particles of arbitrary spin, and derived the commutation relations satisfied by the β-matrices of the wave equation. I published six papers on this subject. Bhabha who was in Edinburgh at the time wrote to me enquiring if he could come to Bangalore and work with me on these topics. I readily agreed, and for a period of three to four years myself, Bhabha and Harishchandra worked together on the topic of relativistic wave equations, but published mostly individual (not joint) papers. Later, Bhabha left Bangalore to undertake work connected with the establishment of the atomic energy establishment, and Harishchandra (who died recently) left for Princeton, where he did very significant work on Lie groups. I continued to work on the subject, and a paper of mine published in the *Proc R Soc* relating to particles of spin 3/2 raised some points which have not been solved up to now. References to my work are to be found in (i) E M Corson's book (Princeton University Press, 1953) in which "Madhavarao algebra", and "Madhavarao's ring" are referred to extensively, (ii) correspondence with N Jacobson on the subject, (iii) in six papers published by Krajcik and Nieto in the *Physical Review* (1975-77), where a special mention is made of my work on particles of spin 3/2 and also in several other papers published by various other authors working on quantum statistics, and the Pauli exclusion principle. On the basis of this work, I was awarded the Ramanujan Prize of the Madras University in 1965.

(5) A joint paper was published along with Bhabha in 1945 on the scattering of charged mesons.

(6) A paper on a conjecture of Ramanujan in number theory published in the *Proc Benares Math Soc* in 1952 attracted the attention of some workers in number theory.

(7) Being out of touch for the last three decades with the rapid developments in physical theories, specially the unification theories, I have undertaken work on recreational mathematics during the last three to four years, and have almost completed a book on magic squares wherein I have highlighted the work on the subject contained in the last chapter of the book entitled Ganitha Kaumudi in Sanskrit written in 1356 A.D. by Narayana Panditha, and also the work on magic squares done by Ramanujan while he was a school student.

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C K Majumdar

The study of solids and liquids, generally subsumed under the title 'condensed matter', has been growing since 1950. Majumdar has worked in several areas of the quantum many-body problem and statistical mechanics of condensed matter.

(A) Positron Annihilation in Metals

Normal metals are characterized by a sharp Fermi surface, that is, a surface on which a discontinuity in the electron momentum distribution occurs at the absolute zero temperature. A positron thrown into a metal annihilates with an electron; most of the time, two gamma rays emerge in nearly opposite directions. The Fermi surface, as Majumdar[1] proved, shows up as a sharp break in the angular correlation curve of the gamma rays. As the temperature of the metal is raised, the positron picks up thermal motion quicker than the electrons which are restricted by Pauli's exclusion principle. But its effective mass is different from the free mass, as the electrons also move in response to its motion. Majumdar[2] proposed that the effective mass be measured from the temperature dependence of the angular correlation curve. The experiment has yielded the effective mass of positron in several metals.

By using counter arrays in the angular correlation, the distribution of two components of momentum can be obtained. This is called the two-dimensional angular correlation of annihilation radiation (2DACAR). Majumdar[3] showed how the data could be analysed to yield more information. In the last decade, the 2DACAR experiments have been done all over the world.

(B) Magnetism

According to Heisenberg, the Hamiltonian describing an insulating ferromagnet is

$$H = -2J \sum_{i,j}{}' \mathbf{S}_i, \mathbf{S}_j \qquad \ldots (1)$$

The magnetic moment of an atom is along its spin $\mathbf{S}$. The interaction energy of the (i, j) pair depends on the scalar product of the two spins $\mathbf{S}_i$ and $\mathbf{S}_j$. J is the exchange constant, usually measured experimentally. The energy in the condition represented by Eq. (1) is minimum when the magnetic moments are all parallel; this gives the large magnetic moment of the ferromagnet. If one spin is turned over, it moves around creating an excitation called 'spin wave' or 'magnon'. If two spins are overturned, they can move independently or move remaining side by side. The latter is a 'magnon bound state'. Majumdar[4] observed that the problem of three overturned spins can be attacked following the theory of the quantum three-body

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problem developed by the Russian mathematician Faddeev. When all the spins are arranged in a line—the linear chain—the equations can be solved analytically for the three-magnon bound state[5]. The higher dimensional problem has so far been attempted numerically.

If J is negative in Eq. (1), the Hamiltonian describes an antiferromagnet. The ground state cannot be written explicitly. For the linear chain ($J > 0$),

$$H = 2J \sum_{i=1}^{N} \mathbf{S}_i, \mathbf{S}_{i+1}, (M + 1 \equiv 1), \quad \ldots (2)$$

the ground state and some excited states have been obtained by the celebrated Bethe ansatz. Majumdar and his student, D K Ghosh, discovered an antiferromagnetic model Hamiltonian[6]

$$H = 2J \sum_{i=1}^{N} \mathbf{S}_i \cdot \mathbf{S}_{i+1} + J \sum_{i=1}^{N} \mathbf{S}_i \cdot \mathbf{S}_{i+2} \quad \ldots (3)$$

($N + 1 \equiv 1$, $N + 2 \equiv 2$) for which the ground state can be written down explicitly. Many properties of the antiferromagnet can now be studied[7]. Eq. (3), often referred to an 'Ghosh-Majumdar Hamiltonian', has also been used in polymer dimerization work, for the ground state is formed by spin pairs or 'dimers'.

In recent years, Majumdar and his coworkers have been utilizing the Mössbauer effect to study the iron ores in eastern India and the phenomenon of corrosion in iron. In particular, they have measured the diffusion constant giving the rate of corrosion[8].

(C) Statistical Mechanics and Many-Body Problem

The quantum many-body problem has some peculiar features. Kohn and Majumdar proved[9] a theorem (the 'Kohn-Majumdar theorem') of the continuity between the bound and unbound states in a Fermi gas. In the single atom probelm the change is not continuous.

Recently, considerable progress has been achieved in the theory of phase transitions through series expansion, Padé approximants and renormalization group. Some universal features in critical phenomena have been recognized; for example, the critical indices depend only on the dimensionality of the system and the number of components of the order parameter but not on the specific system. Majumdar[10,11] devised a variant of the series expansion method. It looks at the zeros of the cluster integrals in the complex plane of some suitable variable and determines the critical parameters and indices. The method is partly analytical and partly numerical; these numerical results are more properly described as conjectures to be proved later. The advantage of the method is that it is applicable to discrete models like the Ising model, ferro or antiferromagnetic[12,13], as well as continuum models like the gas-liquid transition[14]. The calculations of the critical parameters and some critical indices of the gas with the pair potential having the Lennard-Jones form agree well with the empirical data for inert gases[14].

The statistical mechanics of disordered solids is another interesting field developing rapidly. When the time dependence of the stress relaxation in ordinary glass was recognized by R

Douglas, S F Edwards and other workers, Majumdar[15] found a simple explanation for the form of non-exponential decay and a formula that produced the right order of magnitude of the long time scales involved.

Selected Publications

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15. Majumdar C K, Stress relaxation function in glass, *Solid St Commun*, **4** (1971) 1087-90.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R C Majumdar

The main contributions of Majumdar are discussed below in brief.

(1) X-Rays

Majumdar demonstrated Raman Effect in X-rays, the theoretical possibility of which had been discussed by Sommerfield [*Atomban and Spectral-linen*, **2** (1951)].

(2) Statistical Mechanics

Majumdar developed relativistic Bose-Einstein and Fermi-Dirac statistics[1], which were largely used by Milne, Eddington, Chandrasekhar and others for the study of the properties of white-dwarf stars.

(3) Astrophysics

(i) The theory of opacity-coefficient of a degenerate gas was first formulated by Majumdar[2]; it was applied by Milne to explain Jeans' paradox about the internal temperatures in white-dwarf stars.

(ii) A new theory of planets was developed by Majumdar jointly with D S Kothari[3,4]. The significance of the work was elaborted by Sir James Jeans in *March of Science*, 1931-35.

Majumdar published several papers[2–6] in astrophysics, singly and jointly with D S Kothari.

(4) Ionospheric Physics

(i) Majumdar derived a basic formula for the dissociation of molecules in the upper atmosphere[7]. It was shown that the oxygen molecules are completely dissociated at a height of about 100 km [Mitra S K, *The upper atmosphere*, Chap V].

(ii) Majumdar derived the generalized Appleton-Hartree dispersion formula for the propagation of radio-waves in the ionosphere, incorporating the effects of the distribution of electron velocities and velocity dependence of collision frequency[8]. The formula is successfully applied in the solution of all problems of radio-wave propagation in the ionosphere.

(iii) Majumdar obtained for the first time the formula for the frequency of collision between electrons and ions and applied it successfully for the solution of ionospheric problems[9].

(iv) The theory of radiowave propagation in ionospheric plasma was developed by Majumdar[10].

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P M Mathews

An outline is given here of certain selected aspects of the research work done by Mathews over a period of a little over three decades in various areas of theoretical physics.

Relativistic Field Theory

The mechanisms underlying the phenomena of high energy elementary particle physics are understood currently in terms of quantum field theory, wherein various particles are visualized as quanta of associated fields. An endless variety of choices of fields are possible for a particle of given spin and mass (each with its own kind of behaviour under the Lorentz transformations of special relativity and with a corresponding "free" field equation). The simplest available one is the natural and the most usual choice.

But when particles with spin > 1 are involved (and in certain respects even for spin $= 1$), this results in a variety of consistency problems and pathologies; of these, a mathematical inconsistency arising in the quantization of spin 3/2 fields in the presence of electro-magnetic fields (discovered by Johnson and Sudarshan in 1962) is one of the earliest, and the most striking one. Following a rather extensive investigation of consistency problems in particular theories[1], we were able to make a major contribution to the understanding of pathologies of relativistic wave equations with interaction, by exposing the role of their general algebraic structure (i.e. the algebraic properties of the materices β in the general linear form of such equations [viz.$(-i\beta(-i\beta^{\mu}\partial_{\mu}+m)$ $\Psi =$ interation terms] in the causation of specific types of pathologies[2]. With attention focussed on the algebraic aspect, and knowing that the algebraic properties depend very much on the Lorentz transformation behaviour of the field entering the free field equations for the particles concerned, we were led to pose the question: Could the use of less-than-the simplest fields (perhaps even a multiplicity of them) make it possible to construct an equation with congenial algebraic properties needed for freedom from pathologies on the introduction of interactions? This led in turn to the question as to how many really inequivalent field equations (with what kinds of algebras) could one construct for a given type of particle, if one allowed a certain limited number (say 2 or 3 or 4) of different types of fields (each occurring any number of times (*a priori*) to enter into the field equation? And what would their algebraic properties be? The classical formulations of relatistic wave equations (e.g. Dirac; Rarita and Schwinger; Bhabha) either started with specific types of wave functions, or imposed an algebra which then determined the physical content (e.g.

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particle mass and spin) of the equation. An investigation in such generality as we have undertaken (with the physical requirements as basic inputs) had not been made before. Our results so far include a general classification of inequivalent equations involving up to three different types of fields (including a determination of the admissible multiplicities of each field) for describing particles of unique spin and mass[3]. Their algebraic structure and permissible interactions are yet to be investigated; and generalization to cases with more than three distinct types of fields needs to be carried out. These form a major part of our research programme for the immediate future.

The above line of work was an outgrowth from our earlier studies[4] which led to the formulation of relativistic wave equations for arbitrary spin in a standard (though not manifestly covariant) form $i\hbar \frac{\partial \psi}{\partial t} = H\psi$ and the determination of restrictions imposed on these by requirements of invariance under discrete operations such as P, C and T[5]. One of our important accomplishments in this context was the construction[6] of what is perhaps the most general and at the same time the most direct proof of the celebrated spin-statistics theorem—a proof which rests on a spectral representation obtained by us for two-point Wightman functions of fields transforming according to arbitrary representations of the Lorentz group. Unlike earlier proofs, it does not use the complex extension of the Lorentz group or the analyticity properties of Wightman functions. Another general result of considerable significance which has been established by us[7,8] is that the indefinite metric arising in quantum theories of massless fields is a direct and inescapable consequence of the indecomposability of the Poincaré group representations realized over such fields.

Stochastic Processes and Master Equations

The research into stochastic processes dealt with two broad aspects: the application of stochastic theory to specific problems, and the development of mathematical techniques for stochastic theory (in particular, for integrals involving random functions and solutions of differential equations involving random parameters). The application to the then-important problem of the fluctuations in the numbers of electrons and photons in cosmic ray showers was a pioneering work[9], which showed that the fluctuations were comparable to those for Furry processes and thus much larger than the Poissonian fluctuations which had been assumed till then. The mathematical methods included a technique for obtaining solutions for a certain class of difference-differential equations in which the difference is with respect to a continuous variable, by formally solving it by treating this variable as integer-valued, and then using certain operational rules to extend the validity to the continuous case[10]. The use of sample trajectories of a stochastic variable to set up an equation for the probability distribution of integrals involving the variable[11] has turned out to be quite powerful in applications.

Nonequilibrium processes resulting from interactions among sub-systems of a very large dynamical system can be described for most practical purposes by stochastic equations. Our formalism leading to the derivation of master equations for such processes in all generality[12] has been recognized as an important contribution and has been included in a collection of selected important papers on the subject. A later piece of work[13] constitutes a significant advance towards the understanding of the steps involved in going over from the Hamiltonian description of time evolution to a master equation (which is irreversible) in the case of a large quantum system.

Other Work

In the course of work on the quantum anharmonic oscillators (which, incidentally, led to the first approximate analytical formula of high accuracy for the energy levels[14], we developed a fast-converging iterative method[15] for diagonalization of matrices whose off-diagonal elements are small (of the order λ) compared to the diagonal differences: the error in the eigenvalues falls off like λ, λ^3, λ^7, λ^{15}, . . . in successive stages.

On the padagogic side, our definitive paper on the apparent visual forms of objects moving with relativistic speeds[16] has brought to an end the long continued controversy on the subject (and has been cited in the News and Notes Section of *Nature*).

Finally, a book entitled "*A textbook of quantum mechanics*" with K. Venkatesan as coauthor has won wide appreciation and acceptance.

Selected Publications

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M G K Menon

Menon took his BSc from the Agra University (Jaswant College) and MSc from the Bombay University (Royal Institute of Science). He obtained the PhD degree of the University of Bristol, UK, working under Prof. C F Powell, FRS, Nobel Laureate, at the H H Wells Physical Laboratory. He was recipient, from 1953 to 1955, of the Senior Award of the Royal Commission for the Exhibition of 1851. He has received the DSc (h.c.) of 11 Indian universities and from the Indian Institute of Technology, Madras; and Hon Doc in Engg of Stevens Institute of Technology, USA.

Joining the Tata Institute of Fundamental Research, Bombay, in 1955 as Reader, Menon rose to the positions of Associate Professor (1958-60), Professor and Dean of the Physics Faculty(1960-64), Senior Professor and Deputy Director (Physics) (1964-66) and Director (1966-75). He set up the Electronics Commission of the Government of India in 1971; and was its Chairman and Secretary to the Government of India, Department of Electronics from 1971 to 1978. He was Scientific Adviser to the Minister for Defence; Director General, Defence Research and Development Organisation and Secretary in the Ministry of Defence for R & D during 1974-78. He has held several key positions in the Government of India, several of them concurrently: Secretary, Department of Environment (1980-81); Chairman, Indian Space Research Organization (1972-73); Director General, Council of Scientific & Industrial Research (1978-81); Secretary, Department of Science and Technology (October 1978-April 1982); and Chairman, Commission for Additional Sources of Energy (1981-82). Currently, Menon is Scientific Adviser to the Prime Minister, and also Member, Planning Commission with the following areas of responsibility: scientific research and technology development; health and family welfare; ecology and environment; forests and wildlife; minimum needs programme; nutrition; education; and social welfare. He is also Chairman of National Science and Technology Entrepreneurship Development Board; and Vice-Chairman, National Council of Science and Technology Communication.

Scientific Work

Menon's principal scientific contributions have been to: (1) the development of nuclear emulsion techniques; (2) elucidation of the properties of the strange particles; (3) cosmic ray studies near the geomagnetic equator at high altitudes; and (4) deep underground studies in India relating to muons, neutrinos, weak interactions and nucleon decay.

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Nuclear Emulsions and the Physics of Elementary Particles (University of Bristol, UK)

Menon's research work at Bristol dealt with developments of nuclear emulsion techniques and their application to the study of elementary particles. His work (principally in collaboration with Prof C O'Ceallaigh, now at the Institute for Advanced Study, Dublin), was on the refinement of the multiple scattering technique and the use of range vs scattering/gap counts for mass determination of slow particles. These technical developments were instrumental in demonstrating, for the first time, the existence of muons of varying energies, of mono-energetic high energy charged pions, and of electrons (with Friedlander, Keefe and Van Rossum), as secondaries in the decays of heavy mesons (referred to as K-particles); these observations were significantly responsible for establishing the $K_{\mu 3}$, $K_{\pi 2}$ and K_{e3} modes of decay.

Other important aspects of research during this period include: the extension of nuclear emulsion work to stacks of very large size (up to 15 litres in 1954), principally by his colleagues in the Bristol Group and Prof. M Merlin of Padova; and the resultant physics that emerged from the UK-Italian-Irish-Danish G-Stack collaboration; and the first demonstration of scattering phenomena involving the K-particles and discussion of this in terms of the "strangeness" concept which had just then been introduced theoretically by Prof. Gell Mann; he introduced the terminology of "associated production" for strange particles.

High Altitude Balloon Studies (Tata Institute of Fundamental Research, Bombay)

The high altitude balloon programme was developed and brought to a point where it has now become available as a dependable facility for primary cosmic ray work. This was accomplished with his colleagues V K Balasubramaniam, G S Gokhale and R T Redkar. Balloons of several million cu ft in volume; altitudes of around 110,000 ft; gross lifts handled in the region of 600 kg; and a very high percentage of recovery (over 95%) were all achieved in a few years by the early 1960s. The manufacture of balloon grade polymer was established in Bombay and film extreuded under quality controlled conditions; balloon production by staff of the Tata Institute of Fundamental Research was established. Launching, tracking, recovery and all other relevant (largely electronic and electromechanical) capabilities were set up. This is a fairly unique situation anywhere in the world; elsewhere, many of these facets are handled by separate industrial undertakings/facilities. These facilities have been developed further in the years that followed and are used on a regular basis by groups from abroad (e.g. USA, USSR, Japan). Using the balloon facilities, studies were conducted on the primary cosmic radiation close to the geomagnetic equator with electronic detector systems employing scintillation, solid and gas Cerenkov counters, etc.

Deep Underground Studies in the Kolar Gold Fields (Tata Institute of Fundamental Research, Bombay)

Since 1960, Menon has been connected with the growing programme of deep underground observations on particle intensities, angular distributions and other related phenomena in the Kolar Gold Mines in South India (which go down to depths of 2 miles below the earth's surface). He was the Rapporteur/Invited Speaker on the topic of Muons and Neutrinos at several International Cosmic Ray Conferences: Kyoto (1961), Jaipur (1963), Calgary (1967) and Hobart (1971). In 1963, with his colleagues (Professors Narasimham, Ramana Murthy and Sreekantan) and Prof. S Miyake (of Japan), the feasibility and interest in experiments on neutrino and related new phenomena at great depths underground was established. Thereafter, a collaborative experiment involving Tata Institute of Fundamental Research, Osaka City University and Durham University (UK) was carried out (1964-70), in which interactions due to natural neutrinos were first observed and analyzed. Throughout the 1970s, the Tata Institute of Fundamental Research-Japanese collaboration experiments have been in progress. Significant results from these and the earlier experiments include: the observations on the so-called multiparticle "Kolar events" which cannot yet be explained on any known basis and could represent unknown particle decays or other types of new phenomena; evidence that the Utah(US) results (later withdrawn) that muons are significantly produced directly at high energies cannot be correct; and many other aspects of cosmic ray phenomena relating to muons.

Proton Decay (Tata Institute of Fundamental Research, Bombay)

The most recent (and continuing) experiment relates to a 140 ton detector operated at a depth of ~ 1½ miles below the earth's surface in the Kolar Gold Fields with which it is possible to search for the stability of the nucleon up to life times of 10^{31} years; some candidate events, including high quality confined events, have been seen recently which are suggestive of nucleon decay; the nucleon life time appears to be $> 10^{31}$ years. This was the first major dedicated experiment to look for proton decay at these life times anywhere in the world. The experiment involves groups from the Tata Institute of Fundamental Research and Japan (under Prof. S Miyake). Recently, a 400 ton calorimetric detector has been commissioned in a new large excavated halt at the 70th level as part of the continuing programme of experiments on proton decay.

Menon is a Fellow of the Royal Society, London; Member, Pontifical Academy of Sciences, Rome; Hon. Foreign Member, American Academy of Arts and Sciences; Hon. Foreign Member, USSR Academy of Sciences; Founding Fellow and Vice-President, Third World Academy of Sciences; Hon. Member, Institution of Electrical and Electronics Engineers; Member, Board of Governors, International Development Research Centre, Canada; Member, Governing Council, UN University, Tokyo; Fellow, Indian Academy of Sciences (its President during 1974-76); and Fellow, Indian National Science Academy (its President during 1981-82). He was General President, Indian Science Congress Association during 1981-82.

Menon has been associated with several international agencies: Member, UN Secretary General's Advisory Committee on the Application of Science and Technology for Development (1972-80) and its Chairman for several years;

Member (1964-75), Secretary (1971-73) and Chairman (1973-75), Cosmic Ray Commission of the International Union of Pure and Applied Physics; Vice-President, International Union of Pure and Applied Physics (1981-84); and Chairman, Preparatory Committee for the UN Conference on Science and Technology for Development (Vienna, August 1979).

Notable among the awards won by Menon are: Shanti Swarup Bhatnagar Award of CSIR (1960), the G P Chatterjee Award of Indian Science Congress Association (1984); C V Raman Gold Medal of the Indian National Science Academy (1985); the Fourth J C Bose Triennial Gold Medal of Bose Institute; Pandit Jawaharlal Nehru Award for Science of MP State Government (1983); O P Bhasin Award for Science and Technology (1984); Kerala State Committee Prize for Science and Technology (1979); Khaitan Medal (Royal Asiatic Society); and Cecil Powell Medal (European Physical Society). The national awards conferred on him are: Padma Shri (1961); Padam Bhushan (1968); and Padma Vibhushan (1985).

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A N Mitra

It is difficult to be objective when it comes to describing one's own activities in his field of research, for more often than not, the task of projecting a collection of trivialities as an integrated theme is in itself a highly subjective experience. This is an inherent limitation which most research workers (from Alpher to Zacharias) must face in different degrees, and this worker cannot be an exception. Nevertheless, if on looking back, an underlying thread of unity does become discernible, so as to suggest an integrated theme, the possibility suddenly opens up for viewing the work of a lifetime in a new light, irrespective of the initial research motivations. It is from such an angle that I feel inclined to describe the main thrust of my researches over the last 25 years or so.

It all began with the purely mathematical exercise of obtaining an "exact" solution of the nuclear three-body (3N) problem with the so-called separable potentials which had been shown to yield simple and exact results for the two-nucleon (N-N) problem [Yamaguchi Y, *Phys Rev*, **95** (1954) 1628]. This was not to belittle the traditional insolubility of the 3-body problem with coulombic potentials, be it for planetary motion or atomic helium. For the nuclear case, the arbitrary choice of the N-N potential has for long been dictated by the exigency of poor theoretical understanding of the nuclear forces, in contrast to, say, that of the e.m. interaction. Mitra[1,2] had emphasized that such ignorance in the nuclear case could be turned to advantage through a simple enough choice of the N-N potential, which could nevertheless be made to yield other important dividends, especially a "closed-form" structure for the three-nucleon wave function; The latter not only facilitates the calculation of exact amplitudes for a whole range of 3-body phenomena (from energy levels to complex break-up processes), but from a deeper theoretical angle, it incorporates a full knowledge of the off-energy shell behaviour of the N-N interaction. This vital information may appear trivial for, say, an atomic system whose dynamics is governed by a sound theory (electromagnetic), but it offers a most valuable probe into the empirical structure of nuclear physics whose theoretical foundations must be continually refined through a sort of "outside-in" strategy, in contrast to the "inside-out" philosophy usually adopted for "accepted" theories (such as electromagnetic).

The exact solution of the nuclear 3-body problem initiated by Mitra[1] with separable N-N potentials which was in keeping with the physics perspective outlined above, opened up a whole vista for an in-depth study of diverse 3-body systems involving much richer physics than had been possible with the earlier approximation

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(variational) methods. It coincided with the appearance of the more formal Faddeev theory [Faddeev LD, *Sov Phys, JETP*, **12** (1961) 1014] which in practice however had to rely on the separable approximation [Lovelace C, *Phys Rev*, **B135** (1964) 1225] as had been originally advocated by Mitra[1] for a concrete implementation of the 3-body programme. This new perspective in nuclear physics generated worldwide activity on different aspects of few-nucleon problems, which has continued unabated since the mid-sixties. Mitra and coworkers[3–5] also participated in the programme, but were increasingly handicapped by computer limitations compared to their western counterparts, and had to abandon the active race on the "nuclear" front. However, as was emphasized by Mitra (in his concluding summary at the 4th Few-Body Conference at Budapest, 1971)[6], and elsewhere[7], the basic point had been made: the three-body problem holds the key to an "external" understanding of an otherwise empirical N-N interaction, pending a deeper theoretical insight into its structure.

Since the mid-sixties, Mitra got increasingly involved in a new kind of 3-body problem arising out of the discovery of three-quark (3q) constitution of nucleons just around that time [Gell Mann M, *Phys Lett*, **8** (1964) 214]. Formally, the subnuclear 3q problem is similar to the nuclear 3N problem, but the physics now goes beyond the simple "arithmetic of three" and reveals the growing dynamical importance of the three-body problem as one traverses inwards from nuclear to subnuclear[7]. This is the result of the confining role of the hidden quantum number called 'Color', which forces the quarks to stay in colorless bunches with a minimum of three, a dynamical constraint which has no counterpart at the nuclear level of the 3N problem. Nevertheless, the formal similarity of the two systems enabled Mitra to employ the 3-body techniques developed at the nuclear level to investigate the quark structure of hadrons, and he obtained the following significant results in quick succession:

(*i*) Non-oscillatory behaviour for proton form factor as a pointer to an extra quantum number (subsequently to be identified as color[8];

(*ii*) Quark-recoil effect as a means of understanding enhanced s-wave decays of excited baryons and mesons[9];

(*iii*) A new classification of baryon excitations so as to be in conformity with the (observed) absence of 20-type states[10].

During the seventies, Mitra was engaged in a semi-phenomenological formulation of relativistic hadron couplings within a unified mathematical framework at the quark level, using some additional principles, such as Partial Symmetry [Schwinger J, *Phys Rev Lett*, **18** (1967) 923] and the Quark-Pair-Creation hypothesis [Le Yaouanc A *et al.*, *Phys Rev*, **D8** (1973) 2223]. (This involved the language of a "few-quark system", as a modest extension of the "3-body" theme.) Most of these results are incorporated in a review[11] and a monograph[12] which also summarize the contents of the individual research papers on this subject.

Since the beginning of the eighties, Mitra has been engaged in developing a more formal dynamical basis for the spectra of few-quark systems as well as an integrated framework for relativistic hadron couplings in the few-quark language. In his quest for a practicable theory, he has been able to exploit the growing importance of the language of field theory and quantum chromodynamics (QCD) to give a QCD-oriented formulation of q-$\bar{q}$ and q-q interactions directly in terms of Bethe-Salpeter equations for few-quark systems[13,14]. The Bethe-Salpeter equations which naturally provide the relativistic dynamics especially appropriate to light (u, d, s) quarks have not only shown the possibility of automatically incorporating the above principles of Partial Symmetry and Quark-Pair-Creation[15,16], but proved enormously successful in correctly predicting a large class of hadronic properties (their spectra as well as pionic and e.m. couplings[17]). The Bethe-Salpeter model, which thus provides an accurate description of the underlying hadronic dynamics, was, curiously enough, found to yield a much longer life-time for proton decay than most other theoretical estimates (with far less comprehensive dynamics)[18]. The continued lack of positive events till date on a worldwide scale does not seem to be necessarily inconsistent with this simple result without prejudice either to Su(5) GUT theories or alternative theoretical scenarios (supersymmetric or otherwise). The harmonic confinement has been shown to be amenable to a fully covariant formulation in terms of null-plane variables[19].

Finally, it is tempting to mention the prospects of yet another 3-body problem at the sub-quark level. Despite their invisibility, quarks have so far remained the foremost contenders to elementarity in company with the photon, the gluon, and perhaps the leptons. However, with the discovery of three generations of quarks and leptons (and with occasional new "events" in the CERN supercollider), the possibility of their own compositeness in terms of common sub-structures has been slowly gaining ground. While a consensus on these sub-structures (preons) is yet to emerge, it has been argued that they must be fermions and hence constitute a triplet structure at minimum[7]. And this brings one to a fourth generation three-body problem whose dynamical role is even stronger than for the corresponding quark level problem. Using the 3-body techniques with Bethe-Salpeter dynamics[20], Mitra recently found that a preon model of quarks and leptons could provide a simultaneous understanding of their (*i*) spin-half character, (*ii*) 3-generation structure, and (*iii*) steeply rising mass patterns.

The above result seems to bring out a generally accepted truism that major observational trends in a system often lend themselves to mere quantum mechanical formulations with simple-minded inputs, without the need for the full-fledged machinery of a field theory most of whose degrees of freedom play only a passive role in the underlying physics. More important for the "theme" of this narrative seems to be a continuous resilience of the three-body problem with an increasingly active dynamical relevance as the structure of matter unfolds inwards in the sequence atomic → nuclear → hadronic → quark-lepton. The question next arises as to whether the sequence stops at the quark-lepton stage or continues *ad infinitum*. In either case, the experience so far gathered on the increasingly active role of the three-body problem at successively deeper layers of compositeness, would seem to suggest that this problem will continue to have a place under the sun, provided it is adapted to the changing physics scenarios of successive sub-structures. And this, without further ado, hopefully defines enough future work for the three-body problem, in terms of both physical insight at each new stage of compositeness and mathematical technology for the abstract equations.

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A P Mitra

Mitra has been one of the principal figures behind the development of a strong base of *radio science* research in India. He has led *ionospheric research* for three decades. Besides, he introduced tropospheric radio research in India in the seventies using SODAR, low angle satellite radio beacon reception, microwave radiometry and microbarographs. He also catalyzed the development of time and frequency standards in India and has formulated and is now guiding the Indian Middle Atmosphere Programme.

Starting with the IGY, Mitra introduced the cosmic radio noise technique for exploring the ionosphere (including the topside ionosphere inaccessible to classical techniques). He then added new techniques as opportunities came, e.g., satellite radio beacon transmission with the availability of COSMOS V and S-66 satellites; radio beacons at low angles for monitoring large scale tropospheric disturbances (undetected until then); SODAR for mapping tropospheric radio ducts with high resolution as base data for troposcatter systems; microwave radiometry jointly with radiosondes for water vapour and rain attenuation studies; and a whole range of payloads in rockets.

The cosmic radio noise technique (later called "Riometer") was particularly his development. Developed jointly with C A Shain, the method has been in continuous use since the IGY for the study of solar flares for the detection of atmospheric nuclear explosions and has provided a powerful tool for monitoring flare proton bursts at ionospheric altitudes. Mitra showed that at low latitudes (such as those in India) even the normal ionospheric absorption can be monitored, that the topside ionosphere can be explored, that it is possible (especially at low latitudes where F-region contribution is large) to estimate electron temperatures at F-region height, and that it provides additional input for reference ionospheric modelling. Later, with Somayajulu, he put in a riometer receiver in a rocket.

Of the many research activities of Mitra, the following have had significant global impacts:

(*i*) *Ionospheric Effects of Solar Flares*: In a series of six papers published in *JATP*, he and his students reported results of ionospheric flare detection with a wide variety of techniques, examined the physics and chemistry of SID's, pointed out the very drastic chemical changes that occur in the lower ionosphere during those events, developed models of changes of ionization during flares from 60 to 500 km and predicted flare time changes in UV radiation that were later to be confirmed through satellite observations. These, and subsequent papers relating to flare ionization modelling, were brought

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together in a book "*Ionospheric Effects of Solar Flares*" (D. Reidel), the only book of its kind.

(*ii*) *The Lower Ionosphere*: Mitra brought into use a battery of techniques (Riometer, LF and VLF propagation, cross-modulation technique, rocket payloads) to synthesize lower ionospheric ionization profiles and then developed ion chemical schemes that would not only reproduce these but will also predict changes in ion composition under a wide variety of conditions. He introduced a 'six-ion scheme' that was reported in an important paper published in *JATP* to reproduce the major features of the drastic changes in ion composition and loss rate that are observed during flare events, during PCAs and winter anomalies. The scheme has been widely used in different laboratories of the world, and is often employed as an alternative to International Reference Ionosphere. More recently, Mitra has extended this scheme to cover the entire middle atmosphere, as well as to cover conditions such as those relating to ionospheric modification by high power RF heating. The scheme has also been used, with some modification, to estimate inadvertent changes in the mesophere from spacecraft effluents.

(*iii*) *Ion Chemistry*: Mitra's is one of the few effective groups in the world in this area with a whole series of research activities spanning over two decades relating to ion chemistry of the entire ionosphere and the role of nitric oxide in the chemical scheme. These include an extensive set of estimates of nitric oxide from purely ionospheric considerations; ionic schemes for different regions; ionic vs neutral reactions; the not-yet understood sudden collapse of ionization during eclipse totality requiring loss rates that cannot be provided by gas phase chemistry; gradual decrease in loss rate under disturbed conditions that would arise from changes in chemical reaction path; increasing complexity of positive and negative ions as one goes down from mesosphere through stratosphere to troposphere; and the role of middle atmosphere ionization in global electrical circuits. Mitra's report "Chemistry of the Ionosphere" has been widely used in India and abroad.

Mitra has played a vital role in the development of ionospheric research in India. As Secretary of the Indian National Committee, he guided the IGY and the IGSY programmes in India; introduced radio communication predictions that now cover frequencies from a few kilohertz to many gigahertzs and serve all radio traffic organizations in India; established the Associate Regional Warning Centre (ARWC) that helps in rapid dissemination of solar and geophysical data over the Indian subcontinent; guided the development of ionospheric research in many of the Indian universities and universities and institutions abroad; has produced students who now lead ionospheric activities in India and abroad; and has been intimately involved with many international bodies (especially COSPAR, SCOSTEP and URSI).

Mitra has formulated and is now guiding the Indian Middle Atmosphere Programme as Chairman of its Scientific Advisory Committee; he has created and led the internationally known Radio Science Division of the NPL.

Mitra has recently been elected President of URSI (1984-87) (the first Indian and the second Asian to be elected in recognition of his contributions to radio science nationally and internationally. He has had many awards: Bhatnagar Award for Physical Sciences (1968), C V Raman Award, FICCI Award, Nehru Fellowship, etc. He is a Fellow of INSA and Indian Academy of Sciences and is Member of the International Academy of Astronautics.

Mitra has published about 140 research publications and produced and edited several books and monographs.

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B R Nag

Semiconductors became the subject of extensive research after the invention of transistors in 1948. This led to the development of many new classes of semiconductors and at the same time to the invention of myriads of new devices. Nag has been engaged in research in this area since 1960.

Initially, attention was devoted to the development of new techniques for the characterization of semiconductors. New microwave techniques were developed for the measurement of conductivity, dielectric constant, surface recombination velocity and Hall mobility. A critical examination of the accuracy of such methods was also made[1,2].

In 1964, measurement facilities were set up for the study of hot electron transport in semiconductors. Original experimental contributions were made using these facilities on the galvano-magnetic hot electron transport coefficients of germanium and silicon[3,4]. This work later resulted in the development of two laboratories, a microwave solid state devices laboratory and a semiconducting materials laboratory. In the microwave laboratory, solid state sources have been developed using acoustic platelets[5], Gunn diodes and Impatt diodes. Emphasis has been on the development of high power sources using multiple devices. The laboratory is equipped for the measurement of microwave power, spectrum, noise, pushing figure, locking ranges and such other characteristics of sources in the frequency range 2-48 GHz. Work is at present being carried out on the development of high-power sources at 17 GHz and 35 GHz.

In the materials laboratory, work is being carried out on the development and characterization of different kinds of semiconductors. Techniques have been developed for typing[6] and for the determination of crystallographic axes[7] and contact resistance[8]. At present, work is being carried out on the preparation of transparent and conducting tin and indium oxides by anodic oxidation. Facilities have also been set up for the growth of epitaxial layers of III-V compounds by LPE method. Sophisticated characterization facilities are available in this laboratory for low-field and high-field transport measurements, impurity profiling and contact studies.

Work on the development of a theory to explain the experimental results has been carried out all through. The theoretical work has resulted in new methods for the calculation of low-field transport coefficients in nonparabolic polar materials with multiphonon scattering mechanisms[9-11], new methods for the evaluation of warm electron coefficients in

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polar materials and new methods for the evaluation of hot-electron transport coefficients[12]. These methods have been used extensively to study low-field and hot-electron transport in germanium, indium antimonide, gallium indium arsenide and gallium indium arsenide phosphide.

Original contributions have been made on electron statistics in magnetically quantized nonparabolic semiconductors[13], energy bands in superlattices[14], electron scattering in 2-DEG systems and transport in submicron devices[15].

Current interest is in the theory of low-field and hot-electron transport in quantum wells and heterostructures, transport in alloy semiconductors and transient transport and noise in submicron devices.

Work on the theory has resulted in two books[16,7] and a chapter[18] in a book in addition to about 170 papers.

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C Nanjundayya

Cotton has been in use as a textile fibre since ancient times. It has been the principal cash crop of America and India and has contributed largely to the economy of these countries. Scientific research on cotton commenced in India in 1924 with the establishment of the Cotton Technological Research Laboratory (now under ICAR), Bombay. The chief objective was to provide the cotton breeder and the trade reliable estimates of cotton quality. Until then, cotton quality was estimated by the hand and eye judgement of an experienced grader. Obviously, this was open to large subjective error and the judgement differed widely from one grader to another. The first and the foremost objective of the laboratory was to establish scientific methods and evolve control instruments to determine the most important physical and chemical properties of cotton which contribute to its spinning value.

An outstanding contribution was the development of a new method to determine the staple length and fineness of cotton. A new instrument, viz. stapling apparatus[1], was designed for this purpose. This provided a useful tool for the quick determination of the two fibre properties. A global patent was granted for this apparatus, which was used extensively in the cotton breeding stations and testing laboratories. Cotton is a highly variable material, as even a tuft contains fibres of lengths varying from 1/8 to 15/8 in or more. Determination of the proportion of each group length is essential to judge fibre length irregularity. For this purpose, a simple attachment[2] to the stapling apparatus was designed. Further, a simple quartz balance[3] was fabricated.

Cotton is composed of mature or thick-walled and immature or thin-walled fibres. The proportion of mature and immature fibres is determined by swelling the fibres in 18% caustic soda solution and counting the number of fibres belonging to each category under a microscope. This is a laborious and time-consuming method. Therefore, a single dye technique[4], in which the mature fibres are dyed with a deep shade and the immature fibres with a light shade was evolved. This provided a quick estimation of maturity of cotton. Results obtained by the dye method were calibrated against those given by the swelling method.

The physical and chemical properties of cotton depend upon the micro-structure of fibres. Cotton fibre contains both crystalline and amorphous regions. In order to determine the crystallinity of cotton, iodine absorption method[5] was adopted.

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Cotton fibre is composed of fibrils, which spiral round the fibre axis. The angle of orientation[6] was determined by the X-ray method. Results obtained on a number of cottons showed a high correlation between the X-ray angle and the fibre strength. Further, the variation of fine structure of partially benzoylated fibres with increase in the degree of substitution was determined by X-ray method[7].

The non-cellulosic content of cotton is 5-7% and the wax content[8] is 0.3-0.6%. A novel relationship between wax content and surface area of fibres in a unit weight was derived. Surface area per unit weight is proportional to

$$\frac{\text{Ribbon width}}{\text{Fibre weight per unit length}}$$

The wax content is highly correlated to

$$\frac{\text{Ribbon width}}{\text{Fibre weight per unit length}}$$

From this relationship, it was deduced that wax is located on the fibre surface and its thickness is nearly the same for all cottons. The graders attach great importance to the feel of cotton, which is obviously open to very large subjective errors. An extension of the above finding was to classify grades of feel with the intrinsic fineness of cottons.

It is usually assumed that a cotton fibre is uniform in weight along its length, but a specially designed experiment[9] showed that the middle portion is heavier than the basal and apical ends by three times in certain cottons. Therefore, the method of determining fibre weight per unit length was modified. In fact, the mean fibre length determined by the weight-ratio method with the stapling apparatus, mentioned above, takes into account the fact that the middle portion of a fibre is heavier than the ends.

In pursuance of the objective to provide a scientific basis for the determination of factors which influence the behaviour of cotton during processing, a nep counting device[10] was fabricated. Neps are tiny clusters of entangled fibres, which mar the quality of lint and the yarn spun from it.

Frictional forces come into play among cotton fibres during processing. An instrument[11] was constructed to measure it and experiments were carried out on cottons.

The chief objective[12] of the laboratory was to work out the relationship between the measurable fibre characters of cotton and the spinning value so as to be able to predict the latter from the former. Values of the two factors for a large number of cottons were subjected to statistical analysis and multiple regression equations were worked out between them. It was found that 80-90% of the variation in spinning value (as expressed by Highest Standard Warp Counts) could be accounted for by fibre length, fineness and strength alone. This provided an important criterion to predict cotton quality from the relevant fibre properties at early stages of evolving a new and improved variety.

Cotton is hygroscopic and its moisture content varies at different relative humidities, which, in turn, influences the fibre properties, such as fibre weight and strength. A laboratory device[13] for automatically maintaining the required relative humidity in a closed chamber was fabricated. This provided a device for conditioning small samples at a desired humidity for experimental purposes.

Investigations[14] of practical value to the trade and industry were also conducted. For this purpose, commerical bales were stored for two years in a godown. Small representative samples were drawn from them every six months, and fibre properties and the spinning performance were determined. The results showed that no significant change occurred during the period of storage, though there was discoloration. It was, therefore, evident that there was no justification for the grader to undervalue the stored cotton on this account.

Researches were also carried out on cotton during its passage from the field to the market. The seed cotton picked from the plant is subjected to the ginning process in order to separate the lint from the seed. Several investigations[15] were conducted to improve the ginning process so as to minimize the damage done to the lint, which cannot be rectified during the subsequent process.

An economic and technical survey[16] of the existing gins in India was carried out with a view to identifying problems for scientific investigtion. These were related to faulty settings of gins and ginning moist seed cotton, among other things. Remedial measures were suggested. A comprehensive study[17] involving commercial and laboratory valuations of the cotton lint produced with cleaning before and after ginning provided valuable data. Thus, the researches conducted on cotton from the field to the market gave guidelines for avoiding pitfalls in ginning.

The foregoing write-up deals with ginning and assessment of cotton quality from its fibre properties, which involves spinning of cotton into yarn. The developments made in regard to yarn testing are discussed below. Currently, lea strengths of 3 counts of yarn spun from the same cotton are used to estimate the highest standard warp counts[18]. Although the ballistic work of rupture on quarter lea is determined, it does not serve any useful purpose. Therefore, a ballistic tester[19] for use in testing single yarn instead of a strand of yarn was designed. The results of 3 counts of yarn were used to estimate the highest count that could profitably be spun for the first time. Another interesting research[20] was aimed at finding out the yarn structure at the region of rupture. This was done by coalescing the corresponding regions of rupture of the two broken ends. The results indicated that the rupture was generally in the region which had the least number of fibres in the test length.

An outstanding contribution to textile research by Nanjundayya was the establishment of a full-fledged scientific laboratory and a pilot plant with modern instruments, in order to convert cotton and man-made fibres from the raw material stage to fabric, and finish it by chemical processing. This laboratory was set up by the Bombay Textile Research Association (a co-operative research organisation) and opened by the President of India in 1960[21] However, actual work had commenced earlier in a hired building.

The scope of work of this research institute covers the entire field of textile research, comprising fundamental and applied research in mechanical and chemical processing of cotton as well as blends with man-made fibres, operational research, including statistical quality control, human relations, technical liaison for communication of results obtained in the laboratories to the mills and of the day-to-day mill problems referred for investigation to the BTRA laboratories, an up-to-date technical library, dissemination of technical knowledge to mill technicians through bulletins, conferences, seminars, symposia, etc. and textile machinery research and development division for designing new textile machines and manufacturing prototypes, which was started for the first time in India.

A few items of research carried out were: The bleaching of textiles by peracetic acid[22], a substitute for imported sodium chlorite; urea-formaldehyde resin finishing *in situ*, study of a process for imparting crease resistant finish to cellulose fabrics[23]; a chemical, "BIRANOL", prepared to effectively remove oil stains on fabric even while it is on the loom; an electronic instrument[24] developed for measuring tension of the warp sheet during loom operation.

Considerable work has since been carried out in the fundamental and applied fields. A brief account has been given in a BTRA bulletin (1967)[25] and the work done subsequently has been published in various renowned journals both in India and abroad.

Nanjundayya also contributed to the setting up of a textile quality control centre for the Egyptian Government at Alexandria, Egypt, as Project Manager of a large-scale project, financed by UNIDP/UNIDO from 1970 to 1975. This centre was equipped with the latest textile testing instruments and a miniature processing plant for testing of all fibres, including wool and silk. The local staff was trained in handling the equipment and quality control laboratories were established at the textile mills. The final report[26] of the project was reviewed by UNIDO and the Egyptian Government, and implementation of the project was considered to be a syccess. A post-project review made after ten years in 1985 recorded an appreciation of the considerable benefit that had accrued from the assistance rendered by the centre to the Egyptian textile industry.

The foregoing brief account of the pioneering researches covering a wide spectrum of investigations shows the application of science to technology in textiles. Though Nanjundayya is primarily a physicst, it was essential to acquire a sound knowledge of textile science and textile technology, to carry out both fundamental and applied research in this field.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

N A Narasimham

The major areas of research work of Narasimham of importance to fundamental spectroscopy have been: (1) High resolution spectra of molecules of astrophysical importance; (2) Laser spectroscopy and laser spectroscopic techniques for trace analysis; (3) Atomic spectra of rare earth ions in crystalline matrices and garnets; and (4) X-ray spectroscopic studies.

High resolution studies of electronic spectra of atoms and molecules, neutral as well as ionized, are very important not only for gaining an understanding of the electronic structure and electron configurations, but also for identifying spectral species observed in stellar and planetary atmospheres, inter-stellar medium and comets.

Some of the molecules so identified are the hydrides, oxides and sulphides of carbon, nitrogen and phosphorus. Earlier studies of hollow cathode discharges resulted in the discovery and complete analysis of spectra of molecular ions P^+_2, PH^+ and PD^+. Other studies relate to the molecules NH, NS, PS, PO and SO, in each of which several new band systems have been discovered; this work has provided a better understanding of the electronic configurations in the molecules and a correct interpretation of the spectra observed.

Very important predissociations have been discovered in the spectra of NH, NH^+ and S_2, as a result of which precise values for the dissociation energies of the concerned electronic states could be obtained.

Another important contribution is the experimental evidence showing the high pressure carbon bands to be part of the Swan bands of C_2 itself, which aroused considerable speculation and discussion with regard to the emitter as well as the electronic transition.

On investigation of the second negative bands of O^+_2, it is found that the spin-rotation constant changes from a negative value at low vibrational quantum numbers to a positive value for $\nu \geqslant 6$.

Intense emission continua in the vacuum-ultraviolet have been developed through rare gases and employing them as source of continua, several members of Rydberg states in S_2 have been obtained. From an extrapolation of the Rydberg series, the ionization potential of S_2 has been determined and this value has been found to be in good agreement with that obtained from photoelectron spectroscopy.

Another important contribution has been to obtain, for the first time, the well resolved rotational structure of the

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$3\Pi_g - 3\Sigma_u^+$ bands of $^{34}S_2$; from the missing anti-symmetric rotational lines, it has been established that the nucleus of ^{34}S has zero spin. This is quite significant in view of the fact that the microwave spectrum of $OC^{34}S$ only indicated the quadrupole coupling constant and the quadrupole moment of ^{34}S to be very small and this is only an indirect evidence that the spin of ^{34}S is possibly zero. However, the only direct (and unequivocal) evidence is, as described earlier, from the missing anti-symmetrical levels.

Discovery of electronic spectra of halides of xenon and krypton (known to be inert) could be explained satisfactorily with correlation to the ground state doublets of rare gas ions. The diffuse emission bands of xenon and krypton bands are those that provided intense sources of laser emission in the much desired ultraviolet region.

With the advent of lasers, it became possible to explore new fields and to obtain accurate values for the parameters associated with a molecular system. For a proper understanding of the intensity distribution in electronic spectra of molecules and processes like chemiluminescence resulting from recombination of atoms, it is necessary to obtain accurate values of the potential energies (PE) of the electronic states of molecules. The potential energies are usually derived either by employing empirical functions or by using experimentally obtained rotational and vibrational term values. From the potential energies, one can evaluate the Franck-Condon Factors (FCF's) which are the squares of the overlap integrals of the vibrational wave functions of the participating electronic states. These FCF's are used in studying the intensity distribution in an electronic band system. FCF's, together with accurately measured intensities, lead to the determination of electronic transition moment (ETM). Such studies were carried out in the case of the B-X system of I_2 excited by He-Ne and argon ion laser.

Spectroscopic methods and techniques are employed for gaining an understanding of basic phenomena in physical and life sciences. Tunable laser sources and sophisticated detection techniques have contributed vastly to the determination of spectral data accurately. Developments in laser and photodiode technology with the advantage of coherent heterodyne detection in the infrared provide sensitive methods to detect and analyse planetary and stellar atmospheres.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Jayant V Narlikar

(a) *Action at a distance* : Narlikar collaborated with Sir Fred Hoyle in developing an action at a distance formulation of physical interactions. The first step in the process was to demonstrate a self-consistent solution of the Wheeler-Feynman electrodynamics in expanding universes, and to show that the ovserved retarded solution is possible only in the steady state cosmology. The standard big bang models admit self-consistent advanced solutions[1].

The classical electrodynamics was later extended to a full description of quantum electrodynamics and a new light was thrown on the so-called radiative corrections[2,3]. On a parallel front, an action at a distance theory of gravity was also given [*see* (b) in the Appendix for details] and a preliminary step was undertaken to give the action at a distance version of the V-A theory of weak interactions[4]. At present, Narlikar is considering the possibility of describing the electroweak gauge theory in the action at a distance format.

(b) *Conformal gravity* : Starting from Mach's principle, Narlikar and Hoyle formulated an action at a distance theory of 'inertia', which led to a theory of gravity. The theory is conformally invariant[5,6] and under a special conformal frame it reduces to general relativity. However, the appearance of a space-time singularity in general relativity is seen in this theory as the consequence of the existence of a zero mass hypersurface. This leads to a possibility of extension of the relativistic solution past the singular epoch. Other solutions of conformal gravity incorporate variable gravitational constant and the large numbers hypothesis[7]. Canuto and Narlikar[8] have shown that all the present cosmological observations are consistent with this Hoyle Narlikar cosmology. Narlikar has further extended the basic postulates of conformal gravity to be able to explain the anomalous redshifts of quasars[9,10].

(c) *Creation of matter* : In collabortion with Hoyle, Narlikar had investigated the C-field theory of matter creation and its astrophysical and cosmological consequences[11–14]. The ideas proposed in 1966 for the formation of elliptical galaxies, although diverging from the existing mainstream of ideas on galaxy formation at that time, are now seen to contain the germ of truth. It is also found that the bubble universe proposed by Hoyle and Narlikar[13] and the concepts of non-conservation of baryons[12] find echos in the currently fashionable inflationary universe[15].

(d) *Quantum cosmology* : Narlikar has developed a new technique of studying quantum gravity effects near cosmological singularity. This method consists in

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quantizing the conformal degrees of freedom and evaluating the quantum probability amplitude for the evolution of the universe close to the big bang. The important result emerges that quantum uncertainty diverges at the classical singularity, thus rendering the classical solution of doubtful validity. So far as particle horizon and space-time singularity are concerned, it is shown that it is extremely unlikely that the universe could have emerged from a state with these two defects[16,17]. Narlikar and Padmanabhan have reviewed this approach to quantum cosmology in a *Physics Reports* article[18]. This technique is being further generalized.

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Appendix—Relevant References of Other Workers

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S P Pandya

I began my research career in the fields of elementary particles and nuclei in 1950. For the first few years, I worked on meson field theories of nuclear interactions, trying to understand the nature of forces between free nucleons. Later (around 1955), I turned to studies of nuclear forces effective in nuclei. At that time, the best available method to do this was to use the nuclear shell theory. The nature of the effective nuclear interaction forms an important ingredient of the shell theory, which then yields calculated results for nuclear properties, to be compared with the observed data. The typical procedure is to choose a model interaction and vary its parameters, so that the best possible agreement with a given set of data is achieved. I followed this procedure to derive several different model interactions in different regions of the periodic table.

Calculations discussed above also resulted in prediction of other nuclear properties—level energies, spins, parities of nuclear states, etc., which were subsequently verified experimentally.

Another result from these shell theory studies was the derivation of a theorem which closely relates the spectra of nuclei which can be thought of as two nucleons outside a closed shell with those of nuclei which can be thought of as a single nucleon outside and a single hole in the same closed shell. The theorem was obviously useful for predicting nuclear states and also for testing the purity of the wavefunctions assumed. But an even more important result was that it provided for the first time a direct estimate of the contributions of three-body forces in nuclei from observed spectroscopic information.

When I returned to India in 1957, hardly any computing facility was available, and further detailed shell theory calculations were not possible. I then studied collective models of nuclear motion, in particular the interaction of vibrational and independent-particle degrees of freedom in dynamics of nuclei. The first useful applications of this model in d-s shell nuclei ($A = 28$-32) were made by us here.

We also investigated the scattering of high energy electrons by nuclei as well as some simple nuclei in the framework of shell theory.

Later, I developed a novel method of analysing effective nuclear interactions obtained from observed spectroscopic data. A major difficulty hitherto was to make a direct and meaningful comparison of the effective interactions deduced empirically with those seen for free nucleons. The method I proposed isolates the major components of the effective interaction in a form where a direct comparison with those derived from free interactions is straightforward. The

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method also shows clearly how only a few microscopic two-body matrix elements of the interaction (s-state interactions) dominate nuclear spectroscopy, as against the conventional methods where very large sets of matrix elements have to be manipulated to study such spectroscopy. Apart from this, the parameterization proposed by me offered in a very simple and elegant way an understanding of the relative roles of SU_3- or rotation-generating and pairing components of the effective interaction. Prior to this, nuclear theories of rotations employed fictitious quadrupole and pairing forces, and there was no explicit way of expressing realistic interactions in terms of such fictitious components. It has, therefore, also become possible to understand the existence and importance of some of the important group symmetries in nuclei—at least in the mass region up to $A = 90$—in terms of such an analysis of the effective interactions. Now this method is employed extensively.

In the last few years, with the availability of a reasonably large computer system at PRL, I have developed an extensive programme based on self-consistent field theories—which also play an important role in solid state physics, plasma physics and other many-body systems—for studying nuclear properties. We have developed various versions of the Hartree-Fock techniques and large scale programming packets. An important ingredient of our work is the incorporation of configuration-mixing methods of shell theory into Hartree-Fock formalism. This has made the Hartree-Fock technique into a powerful tool for understanding a variety of nuclear properties. These methods have been applied to several different sets of nuclei. An important result is that for the first time there is a consistent description of transition from rotational to quasi-vibrational spectra in neighbouring nuclei, such as ^{20}Ne and ^{24}Ne. One is also able to understand with the help of our approach the stability of deformations to pairing or vibrations, shape mixing, coexistence of different shapes, etc.

In the last few years, extensive applications of this approach have been made in the nuclei with masses in the range $A = 40$ to $A = 90$ (i.e. those where valence nucleons are in f 7/2, p 3/2, p 1/2, f 5/2 and g 9/2 orbits). Many features of the observed nuclear structure for these nuclei have been explained in microscopic framework for the first time, and several new properties have been predicted. The origin of large deformations, coexistence of shapes, existence of different types of bands of nuclear states, etc. have been brought out clearly and related to the properties of nuclear interactions, and of the configuration space as a result of our approach of deformed configuration mixing shell model.

I have also used the powerful methods involving the use of group-theory and statistical mechanics, developed by J B French, to study the relative strengths of quadrupole and pairing components of various effective interactions, and also spectroscopic factors of particle transfer (or pick up) reactions in d-s shell nuclei.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B Peters

I studied physics at the University of California in Berkeley. The second world war broke out before I received my PhD, and during the war my research was concerned with the separation of uranium isotopes in connection with the "Manhattan" atomic bomb project. Through this work, I became interested in cyclotrons which during wartime were used as mass spectrometers; as soon as the war came to an end, I became concerned with the problem of how to use cyclotrons to accelerate particles far beyond the energy region where the relativistic mass increase became noticeable. The solution of this problem, which then led to the production of pions in many laboratories, was frequency modulation[1].

In 1946, I left Berkeley for the University of Rochester N Y and became interested in cosmic radiation, that is, particles of energies much higher than those then available in the cyclotron laboratories. This required observations with the help of balloons in order to intercept these particles before they had interacted with the atmosphere. The first such flight led to a surprise, the discovery of complex nuclei in the primary cosmic radiations[2].

Very soon after that, we were able to study the interaction of particles of energy of several thousand million eV, many orders of magnitude higher than then available in the laboratory and found that those interactions often led to "multiple production", simultaneous production of a very large number of mesons and gamma-rays (which are mostly decay products of neutral pions)[3]. The same events permitted us later to study not only the production but also the interactions of the very high energy secondary mesons and γ-rays in photographic emulsion and in other detectors[4].

At the same time, we explored the chemical composition of the primary cosmic radiation and found that it has great similarity with what was then considered the "universal" chemical abundance of stars and galaxies, except for the fact that the light nuclei lithium, beryllium and boron and a few others were many orders of magnitude more abundant in the cosmic radiation than in the "universe". We attributed this to fragmentation of the more abundant heavier primary nuclei colliding with interstellar gas atoms on their way from their source to the solar system[5]. This permitted us to estimate the time the cosmic ray nuclei have spent on their voyage from the source where they were accelerated to their arrival in the solar system.

Another obvious question to ask was whether cosmic rays contained only nuclei of ordinary matter or also antimatter

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nuclei. To answer this question, I built in Rochester a stabilized balloon platform to be flown near the Equator in order to measure the so-called east-west effect, i.e. positively charged (ordinary) nuclei can penetrate the earth magnetic field easier if they come from the west, while antinuclei were expected to arrive mainly from the east. No antinuclei were found.

But the experiment which had to be carried out at low geomagnetic latitude led me to a collaboration with Dr Bhabha and the Tata Institute of Fundamental Research and later to my working in Bombay for many years.

In studying meson production at high energy, we soon found that there are not only pions among the secondary particles but also what is now called "strange" particles, namely, kaons and hyperons. We determined their masses, decay modes and interaction properties[6].

In Bombay, we also got interested in another aspect of cosmic radiation, namely the fact that in their passage through the atmosphere, collisions with the nitrogen, oxygen and argon nuclei could lead to all kinds of radioactive nuclear fragments with many different half-lives. In a way similar to the already known ^{14}C method, these nuclei could be used to determine the rate of various geophysical processes during which they get removed from the atmosphere and then distributed in the hydrosphere, lithosphere, biosphere as well as sediments on the surface of the earth or on the bottom of the sea. It was shown that tracing such particles through the geosphere is possible even though their abundance is many orders of magnitude lower than that of ^{14}C. The earliest study was on the longlived isotope ^{10}Be ($\tau = 1.6$ My)[7], which is now used widely to study and date sedimentation, land erosion, variations of cosmic ray intensity in the last few million years, growth rate of manganese nodules, etc.

During those years, a number of survey articles were written: on the cosmic ray phenomena in general[8,9], on the use of cosmic ray produced radioactive tracers in geophysics[10], on the complex way in which the cosmic ray energy incident on the atmosphere is distributed among large numbers of mesons, muons, electrons and γ-rays and finally dissipated[11].

In 1958, I left India for Denmark. It was the beginning of the space age which would permit a considerable improvement of cosmic ray measurements, in particular their detailed composition. A suggestion was made for a large satellite capable of carrying out this task[12]. It took nearly 15 years to attain this. Not only the chemical (i.e. charge) composition of the incident nuclei could be measured but also the isotopic composition, which permits analyzing the processes by which these nuclei were synthesized in stellar objects before becoming accelerated[13].

A large and successful satellite experiment on the "High Energy Astrophysical Observatory", HEAO-3, was carried out in 1979 together with Danish and French colleagues[14].

Finally, an attempt was made to fit all known properties of the primary cosmic radiation (i.e. energy spectrum, composition as a function of energy, time variations, anisotropies, properties of extensive air-showers, etc.) into a single picture, a "closed galaxy" model[15]. This model envisages that particles of even the highest energies may not only be accelerated within our galaxy but also retained by it by means of a galactic large scale magnetic (quasi) dipole field, supported by systematic galactic rotation of the partially ionized interstellar gas, which is superimposed on its turbulent motion.

The "closed galaxy" model has not been accepted by the majority of CR physicists, but it has specific features capable of being verified in future experiments. These are: the production inside our galaxy of primary particles with energy above 10^{16} eV/nucleon, the existence of a large scale magnetic field far above and below the galactic disc which carries the generating currents, a radical change at high energy ($\simeq$ TeV/nucleon) in the ratio of truly primary cosmic ray nuclei to secondary nuclei produced in their collisions with the interstellar gas (f.i. Li, Be, B) and a prediction that the heavy nuclei have a much greater anisotropy than the light components. These prodictions may still turn out to be correct and make this model attractive.

In 1967, the Danish Space Research Institute was founded and I was its director until my retirement in 1980. During those years, I served as representative of the International Union of Pure and Applied Physics (IUPAP), on the Council of COSPAR, ICSU's Committee on Space Research, as a member of the Executive Committee of SCOSTEP (ICSU's Committee on Solar-Terrestrial Physics) and also on the Space Committee of the European Science Foundation.

Recently, the Government of India conferred on me Padma Bhushan. I have been a fellow of the Indian National Science Academy, the Indian Academy of Science, the Royal Danish Academy of Science and the American Physical Society since the 1950's.

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E S Raja Gopal

Research in frontline experimental physics often requires the concurrent development of newer measuring techniques and history is full of examples of this symbiotic relationship. At the current levels of competition in condensed matter physics, it requires extra special effort while working in India, but these long hours of toil have their own rewards. Apart from the personal pleasure of achievement, events like the election to the Fellowship of the Academies (1974, 1981), the S S Bhatnagar award (1978), the Sir C V Raman award (1979-80) and the Inventions Promotion award (1984) have demonstrated that this class of work is still recognized in India.

Early in my research career, I was thrown into the controversy then raised regarding the validity of the classical theory of elasticity[1]. Laval with coworkers in France and Raman with coworkers in India suggested that the classical infinitesimal theory of elasticity may require corrections because of the presence of atomic volume torques and the consequent asymmetry of the stress tensor. After some theoretical work, which showed that at best surface torques can give rise to corrections but not volume torques, I turned to the experimental test of the predictions. This required the development of an ultrasonic pulse echo apparatus of about 0.1% absolute accuracy. While the experiments proved that the classical theory of elasticity was quite adequate for experimental purposes, they led to a technique to measure all the 21 elastic constants of a triclinic crystal, copper sulphate pentahydrate being the first triclinic crystal to be solved thus anywhere in the world[2]. The interest in this class of precise measurements led to ultrasonic pulse echo interferometry. Novel electronic circuitry enabled a simple unit to be built with 10 ppm resolution in transit time. The *NRDC Inventions Promotion Award* (1984), shared with Drs K R Srinivasan and M K Gunasekaran of Systems Dimensions Company Ltd, Bangalore, cited this development work. The interest in ultrasonic measurements led to another award. The ultrasonic velocity measurements in DNA and chromatin solutions at high pressures of the order of 3000 atm revealed conformational changes, which had been earlier inferred from osmotic compressibility data[3]. The technique of making these measurements and the results were cited by the Acoustical Society of India for the *Sir C V Raman Award*, shared with colleagues in Physics and Microbiology Departments.

The same motivation of high precision measurements was the objective of developing indigenously ratio transformer-based capacitance measurements of 1

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ppm resolution. Six decade toroids of adequate absolute accuracy have been wound in the laboratory. Recently, the technique has been extended to measure capacitances shunted by appreciable conductances. For example, a 40 pF shunted by 10 kΩ can be measured with 10-100 ppm accuracy at 1-10 kHz[4]. This development opens up the possibility of new investigations in critical point phenomena and high pressures, some of which are being explored.

Whenever precision measurements are attempted, one encounters at the very first stage the need for accurate temperature control. One of the efforts over the past 20 years has been to get better and better temperature control, the present position being a short-term stability of 500 microdegrees under favourable conditions. The classic need for such fine control is the investigation of critical point phenomena, which has been pursued in binary liquid systems. One of the early successes, in 1973-74, was the observation of the breakdown of the so-called rectilinear diameter law, as a result of the failure of the particle-hole symmetry in the system[5]. This had been predicted somewhat earlier, but the first experimental observation was made in India, barely months ahead of the US and USSR scientists. While a number of other investigations have been performed in critical point phenomena[6], this observation was specially cited in the *Shanti Swarup Bhatnagar Award* (1978). The newer activity in this area concerns the critical wetting phenomena. Normally, a heavier liquid rests below a lighter liquid, but under special circumstances, the heavier liquid climbs up the side wall of the container and a pendent drop of the heavier liquid rests on top of the lighter liquid. In a carefully chosen binary liquid system like acetonitrile + cyclohexane, this almost unbelievable situation governed by capillary forces is macroscopically observable[7].

In the last 10 years, attention has been directed to the development of high pressure facilities, in particular Bridgman anvil apparatus capable of going up to 140,000 atm pressure and down to 77 K in temperature. Investigations on chalcogenide semiconducting glasses have revealed several interesting phenomena, especially connected with the glassy semiconductor-to-crystalline metal transformation. In glasses of the GeSe system, the transition is found to be discontinuous at a high pressure of the order of 70 kilobar, while in some glasses, like the AlTe system, the transition occurs continuously as the pressure is increased. In the $Se_{100-x}Te_x$ glasses, the transition is discontinuous for $x < 6$ and continuous for $x > 6$ (ref. 8). A different class of problem is seen in glasses like $Ge_{20}Te_{80}$, $Si_{20}Te_{80}$. At high pressures, one has a polymorphous or congruent crystallization without change in composition. On the other hand, when crystallization is induced by temperature, one finds that at first a part of Te precipitates as crystals in a matrix which remains glassy. At a higher temperature, the matrix also becomes crystallized. The double crystallization in the temperature cycle and the polymorphous crystallization in the pressure cycle are studied by X-ray and electron diffraction methods[9]. Quantitative explanations of these phenomena in glasses are not possible at present, while high pressure phenomena in crystalline materials are explainable on the basis of reasonable theories[10]. The recent investigations include the study of quasicrystals which show local 5-fold symmetry[11].

It is expected that a university teacher passes on to students some of the enthusiasm and thrill in doing research, a rather difficult task in experimental physics. Nevertheless, through books[12], lecture notes, laboratory classes and personal example, I have striven to convey the agony and ecstacy of participating in competitive work.

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R Rajaraman

Rajaraman's research work during the past 25 years has spanned the areas of nuclear many-body theory, elementary particle physics and quantum field theory.

(i) Nuclear Theory

His work on Nuclear matter theory began with his PhD dissertation, completed at Cornell University in 1962 under the guidance of Prof. Hans Bethe, the Nobel Laureate. This theory was being developed to understand large nuclei from first principles, without additional ad-hoc assumptions. Rajaraman's PhD work and subsequent papers examined and criticized the existing approach to the problem, which was essentially perturbative. Instead, he proposed a basic non-perturbative reformulation of the problem, which was subsequently adopted by the field under the name of the "Mole-line Expansion". It forms now the basis of one vast family of calculations in Nuclear Matter Theory by workers around the world. On a different front, he wrote a series of papers on 3-body and many-body forces in nuclear physics, with B McKellar. These papers developed systematic ways of calculating such forces as well as their contribution to nuclear energies. He wrote two widely quoted reviews, one coauthored with Prof Bethe and the other with McKellar on these developments.

(ii) Particle Physics and Quantum Field Theory

In the late sixties, Rajaraman began to enlarge his interests to the field of particle physics. In those days, the main approach to that subject was based on S-matrix theory and Regge theory. Rajaraman made several contributions to this area. He obtained, in the S-matrix framework, a bound on high-energy weak-interaction processes mediated by neutrinos, taking into account special problems introduced by the masslessness of the latter. In Regge theory, he was the first to extract the "triple-Pomeron" vertex from experimental data. He proved the decoupling of the Pomeron pole from all inelastic processes. In a set of papers with J Finkelstein, he obtained relations between different inclusive cross-sections using the exchange-degeneracy of Regge poles. Meanwhile, exciting experiments at the SLAC accelerator produced impressive "scaling" results in high-energy electron scattering, revealing the "quark" structure of the proton. In papers written in collaboration with S R Choudhury and G Rajasekharan, Rajaraman obtained constraints on the scaling structure functions, which describe quark distribution in the proton.

In the mid-seventies, emphasis shifted in the field from S-matrix theory back to

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quantum field theory as the tool for studying elementary particles. Rajaraman adapted to the change in strategy and has since made several contributions to quantum field theory, notably in the area of quantum solitons and instantons. With Weinberg, he was the first to show how solitons with internal symmetry are to be quantized. He developed ways of obtaining new soliton solutions, and to calculate the forces between them. His work with John Bell on fractionally charged solitons clarified this mysterious phenomenon, which also finds application in polymer physics. His review on quantum solitons and his recent book on the subject have both been widely used by the new generation of field theorists.

Aside from solitons, he has worked on the subjects of anomalies in gauge theories. With Kaul, he improved upon ‘tHooft’s anomaly constraints on composite models of particles. More recently, he has shown, with Jackiw, that certain anomalous theories are in fact self-consistent and quite sensible, contrary to the prevailing feeling that they were all necessarily inconsistent.

In the near future, Rajaraman hopes to continue his study of anomalies in gauge theories, and get a deeper understanding of this phenomenon, which has been playing an increasingly pivotal role in particle-theory.

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G Rajasekaran

(1) Shadow Poles

In collaborative work with Prof. R H Dalitz, Rajasekaran showed that a multichannel resonance pole, in general, is followed by a retinue of poles on the various Riemann sheets (of the complex energy plane)[1-3]. This discovery of shadow poles answered a serious objection raised by R J Oakes and C N Yang against the (flavour) SU (3) symmetry and paved the way for the eventual success of SU(3).

(2) The K-Pole Test for Elementarity

He formulated an empirical test for elementarity or compositeness of hadrons and applied it to the case of $\Lambda(1405)$. The test is simply that "elementary hadron" is always followed by a pole in the K matrix. Although he proposed the test as early as 1967[4,5], it took 3 or 4 years to catch the attention of experimentalists and phenomenologists, as a perusal of the literature of 1970-72 will show. In 1971, he undertook a more detailed study of the problem and applied the test to many other hadrons as well[6].

(3) Fixed Pole in Compton Scattering

The existence of a fixed pole in the virtual compton scattering amplitude was discovered by Rajaraman and Rajasekaran in 1971[7]. This led to a flood of literature on the topic during the years 1972-75.

(4) Gauge Theory

In 1971 came the gauge theory revolution. He was a very early proponent of gauge theory and was actively involved in it even before it attracted general notice among high energy physicists. The following facts are adduced in support of this claim.

(a) He gave a series of lectures on "Yang-Mills Fields and Theory of Weak Interactions" at the Saha Institute of Nuclear Physics in June 1971[8]. This was much before gauge theory became a band wagon and in fact it was even before the appearance of the famous paper of t'Hooft showing the renormalizability of gauge theory. (Unfortunately, these lectures were distributed only in the form of cyclostyled preprints and so could not reach a wider audience, which would have been possible if a suitable review journal had been available in this country.) This set of lectures was the very first connected account of a number of topics such as Faddeev-Popov ghosts, infrared problems, Higgs-Kibble mechanism, Weinberg-Salam model, the neutral weak current, the fourth (charmed) quark, etc., all of which became standard topics during subsequent years.

(b) Even more significantly, in the above lectures[8], the following fundamental issues were raised for the first time.

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(i) It was conjectured that the incurable infrared disease of the Yang-Mills theory might prevent the materialization of the zero-mass Yang-Mills quantum as a physical particle. This conjecture, extended to quarks as well, has been sanctified by the names 'Infrared slavery' and 'Colour confinement' in current literature and is now one of the dogmas of quantum chromodynamics.

(ii) It was also suggested that the nonabelian gauge symmetry with its intrinsic instability may be the physical reason for the existence of broken symmetry.

(c) The cancellation of higher-order-correction to muon decay in gauge theory reported by him[9] is one of the very early applications of gauge theory, although it was soon followed by a flood of calculations of this type.

(5) Neutral Current

Soon, attention shifted to the neutral-current weak interaction predicted by Weinberg-Salam gauge model and discovered experimentally. The first purely phenomenological analysis of the inclusive neutral current data without prejudices coming from gauge models or other models was performed by KVL Sarma and Rajasekaran[10]. The equation derived in this paper (referred to as the "master equation" in subsequent literature) played a crucial role in pinning down the coupling constants of the neutral current.

(6) Integrally Charged Quarks

Certain remarkable consequences of the gauge theory of integrally-charged Han-Nambu quarks were discovered and reported by P Roy and Rajasekaran[11–13]. The complex of mixings in this theory had generally discouraged a serious study of this problem and previously nobody had tried to see through the maze of the mixing equations and carry the analysis to its logical conclusions. When these authors did it, the results turned out to be unexpected and interesting. In particular, they showed that although quarks may in fact be integrally charged, they manifest themselves as fractionally charged objects in high-q^2 deep inelastic experiments. This is a direct result of the mixing between gluons and electro-weak gauge bosons. (J Pati and A Salam also studied this problem, but their result contained a crucial error, which was subsequently corrected.)

It needs to be emphasized that although Pati and Salam had earlier proposed unified gauge models based on Han-Nambu quarks, the experimental viability of these models was established only after the discovery of the above result, for up to that time, it had been erroneously thought that deep-inelastic experiments ruled out Han-Nambu quarks.

(7) Hadronic Jets

Rajasekaran and his collaborators in Madras University (T Jayaraman, S Lakshmi Bala, S D Rindani) have now tested the viability of the integrally charged quark model in a variety of more complex situations involved in the "jet" experiments at "PETRA"[14].

(8) Photon-Photon Collisions

It has been concluded by earlier investigators on the photon-photon reactions initiated by e^+e^- collisions that the integrally-charged quark-model is ruled out. T Jayaraman, S D Rindani and Rajasekaran showed that this conclusion is in error because of the virtuality of the photons produced in e^+e^- collisions[15]. As a consequence of this work, it is now recognized that collisions with real photons in the final state are needed to settle the issue of the quark-charge[16,17]

(9) Equivalent Photon Approximation

Equivalent photon approximation is a time-honoured formalism used in the study of electromagnetic processes from the days of Niels Bohr, Enrico Fermi, Williams and Weizsacker. T Jayaraman, S D Rindani dani and Rajasekaran have discovered some new effects which restrict the validity of this formalism when applied to vector boson production in virtual-photon mediated processes[18].

(10) Lectures in High Energy Physics

High energy physics is a frontier area where major developments are taking place. The field is on the verge of breakthroughs in fundamental knowledge. India cannot afford to wait on the sidelines and bright young people of this country must join in this great adventure of ideas. Summer schools and workshops are a means of achieving this aim. Over the years, a large part of his time and energy have been spent in lecturing at these schools and workshops. For instance, in the past one year alone, he have given the following sets of lectures:

(a) Lectures entitled "What is the next step after electroweak unification?" given at the Workshop on Recent Advances in Theoretical Physics held at IIT, Kanpur, in December 1984[19].

(b) Lectures on "Superstring Field Theory" given at the Mini-Workshop on Superstrings held at IIT, Kanpur, in March 1985.

(c) Lectures on "Composite Structure for Leptons and Quarks", given at the DST Summer School on Theoretical High Energy Physics, held at IISc, Bangalore, in April 1985.

(d) Lectures on "Building up the Standard Model of High Energy Physics" given at the UGC Instructional Conference on Gravitation, Gauge Theory and Early Universe held at IISc, Bangalore, in May-June 1985.

Each of these was an extensive course of lectures and was pitched at a different level of pedagogy or research and together they covered a wide spectrum of topics in present-day high energy physics.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

T V Ramakrishnan

(1) Strongly Interacting Fermi Systems

(a) *Kondo and mixed valent systems*: An attempt to understand the highly anomalous transport properties of these systems has been made, and a simple model developed for the Hall effect (in collaboration with P W Anderson and P Coleman). The model explains the anomalous sign, the very large size, and strong temperature dependence of the Hall constant. These effects have nothing to do with the carrier concentration, but depend on the nature of the ground state of these systems.

(b) *Heavy Fermion metals*: Following the discovery of an unusual form of superconductivity in these systems, there is greatly enhanced interest in the physics of strongly correlated *f* electron-based solids. A new approach, treating correlations exactly, has been developed leading to a physically appealing description of the normal phase, going over smoothly from a collection of spins at high temperature to a Fermi liquid with spin fluctuations at low temperature. In mind are applications to superconductivity, competition between superconductivity and magnetic order, Mott transition and the Mott-Anderson transition.

(2) Disordered Systems

(a) *Electron solvation*: The problem of electron solvation, i.e. electron motion in a dense fluid, has been formulated as a band tail localization problem in a medium with annealed disorder. The problem is one of a major class, which includes polaron formation in random systems.

(b) *Amorphous semiconductors*: The question of including the effect of periodicity and of deviation from it on the same footing is being explored. The former leads to energy gaps and to localization of impurity states in the gap. The latter leads to states in the gap. The approach is almost exactly the opposite of that currently available for these systems, i.e. those based on disordered metal ideas and Anderson localization.

(3) Density Wave Theory of the Solid

(a) *Equilibrium*: It has been shown recently that the density wave theory of freezing can be extended to describe phonon frequencies in terms of fluid phase *static* correlation function. This and other applications of the density wave theory are being pursued in collaboration with Prof. Y Singh.

(b) *Glass transition*: In collaboration with Dr S N Gadekar, a mode coupling theory for the kinetics of glass transition is being developed. The increase in viscosity of the supercooled melt has been described by this approach; the glass regime needs new ideas.

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Selected Publications

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P V Ramana Murthy

My research work, which relates to the fields of cosmic rays, high energy physics and astrophysics is all experimental and interpretative in nature. My contributions to physics can be broadly divided into the following categories, in each of which I have identified the more frequently cited papers, being the most original ones:

(A) High Energy Muons Underground[1,2]

I did the first and the most definitive work on variation of muon intensity with depth at depths up to 8400 Hg cm^{-2} in Kolar goldfields. The numerical method to handle fluctuations in energy losses of muons developed here was widely followed by others.

(B) Cosmic Ray-Neutrino Interactions Underground[3,4]

The possibility of observing cosmic ray-neutrino interactions deep underground was first pointed out and later followed by actual observations. Radiation backgrounds from all possible sources studied in these experiments proved useful for later-day proton decay experiments.

(C) Low Energy Muons Underground[5]

A definitive work on stopping muons at various depths underground was done; there have been confusing and conflicting results in the field. The so-called Turin anomaly was explained on the basis of our detailed studies on angular distribution of stopping muons.

(D) Interpretative Research[6]

Several topics in cosmic ray and elementary particle physics were covered in the papers published. In particular, the unexpectedly high μ^+/μ^- ratio, which defied understanding was explained in terms of isobar production (simultaneously with and independent of the work of Yash Pal and Bernard Peters).

(E) Accelerator Experiments[7]

Neutron cross-sections were studied at Fermilab (USA) up to energies of 270 GeV. In particular, the inelastic screening effect inside a nucleus was demonstrated clearly.

(F) New Particle Searches[8]

Several experiments were conducted with the objective of searching for tachyons, massive hadrons and heavy leptons. The work on tachyons was highly original and of trend-setting type.

(G) Detection of High Energy Gamma Rays from Pulsars

Positive signals of ultra-high energy gamma rays from the Crab and Vela pulsars were detected using atmospheric Cerenkov technique.

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(H) Techniques and Methodology[9,10]

A model independent method to measure high hadron energies using a calorimeter was demonstrated, immediately after Grigorov. Now this technique is considered as a standard tool in accelerator experiments. The maximum likelihood analysis of multiple ionization samplings to distinguish protons from pions at high energies was originated and widely adopted by others in cosmic ray and accelerator experiments. Wide fluctuations in energy losses of charged particles in gases were observed and explained.

Several standard review articles on cosmic ray muons, strong interactions at high energies, ultra-high energy gamma rays and neutrinos have been published[11]. In addition, a book has been written jointly with Prof A W Wolfendale, F R S (Durham University, U K) on 'Gamma Ray Astronomy' (Cambridge University Press, in press).

Selected Publications

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8. Ramana Murthy P V, Search for tachyons in cosmic radiation, *Nuovo Cimento*, **1** (1971) 908.
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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Raja Ramanna

Ramanna's research contributions span several areas of neutron, nuclear and reactor physics. As a part of the studies relating to the design and construction of India's first reactor "APSARA", Ramanna *et al.* have studied the process of neutron thermalization in several moderating assemblies[1]. Using a pulsed neutron source, the neutron diffusion and slowing down constants in water and beryllium oxide were determined. The neutron spectra emerging out of these moderating assemblies were also studied[2].

Following the commissioning of the reactor "APSARA", resulting in the availability of intense thermal neutron beams for basic research, Ramanna initiated a programme of experimental investigations of secondary radiations emitted in thermal neutron-induced fission of ^{235}U. Based on a novel hybrid fission chamber[3] combining a gridded ionization chamber for measurement of the energy and angle of the fission fragments, gas scintillations for time measurements and time of flight, the energy and angular distributions of prompt neutrons[4] and gamma rays[5] emitted by the fission fragments were measured. Analysis of these data yielded important results on the times of emission of these radiations, presence of scission neutrons, the average spin of the fission fragments, etc. The investigations by Ramanna and collaborators on light charged particle emission in fission induced by thermal and fast neutrons have similarly provided important information on the mechanism of emission of these particles. For example, the first measurement of the angular anisotropy of these particles with respect to the incident beam direction suggesting an evaporation origin of these particles were carried out in Trombay[6].

Other important investigations carried out by Ramanna and collaborators include the study of the correlation between fragment angular anisotropy and the mass asymmetry in fast neutron induced fission[7], studies of the mean number, multiplicity and times of emission of K-X rays from fission fragments, etc.

The stochastic theory[8,9] of fragment mass and charge distributions in fission is a unique contribution of Ramanna to fission theory. Based on the model of a random exchange of nucleons between the two nascent fission fragments prior to scission, the theory was able to explain most of the observed features of fragment mass and charge distributions in low energy fission and their dependence on the excitation energy of the fissioning nucleus[10]. The nuclear shell effects entered the theory in a natural way through shell dependent nucleon transfer probabilities. The nucleon transport mechanism

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between two nuclei in proximity continues to find widespread application even at present in heavy ion deep inelastic reactions to explain the observed mass and charge variances and their correlation with the energy loss in relative motion. Another novel contribution by Ramanna and collaborators is a geometrical interpretation of atomic and nuclear binding energies[11]

Ramanna's contribution to India's Peaceful Nuclear Explosion experiment is well known. Recognizing the many potential industrial and engineering uses of peaceful nuclear explosions[12], a fully contained experiment was carried out underground in the Rajasthan desert on 18 May 1974, as a step towards studying fracturing effects in rocks, ground motion, containment of radioactivity and the problems involved in post-shot access of the shot-point environment. The results of the experiment were presented and discussed at the 4th IAEA Panel Meeting on Peaceful Nuclear Explosions in 1975[13].

In recent years, Ramanna, as Chairman of the Atomic Energy Commission, has been deeply involved in the planning for future nuclear power generation in the country. It is well known that the demand for electrical energy has been growing exponentially over the years and projections indicate that India will have to nearly treble its present electrical generating capacity by the turn of the century. Paucity of natural non-renewable resources like oil or coal and restrictions on the availability of hydro-potential, leads to the conclusion that these resources alone cannot meet the projected demand for electric power. Based on the technological self-sufficiency attained in the field of nuclear power, the country is embarking under Ramanna's leadership on a 15-year programme for nuclear power with a goal of 10,000 MW set for the end of the century[14,15].

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10. Ramamurthy V S & Ramanna R, *Proc. Second IAEA Symp. Physics and Chemistry of Fission* (IAEA, Geneva) 1969, 41.
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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S Ramaseshan

(1) Diamond and Its Mysteries

The lapidaries of yore knew of the perfect octahedral cleavage of diamond and used this knowledge to advantage. Can laws governing cleavage in crystals be formulated? The energy of cleavage (i.e. the energy required to rupture the bonds connecting atoms on either side of a plane) must be a minimum; and its variation with direction must also be large if the cleavage is to run true. A study of the fractured diamonds in the Raman Collection lent statistical support to these two criteria[1].

Some of the most beauteous objects in nature are single crystals of diamonds from Panna (India) with their exquisite curved faces and delicate tracery of edges. The shapes that crystals take are usually determined by the growth rate of their faces. However, measurements and calculations show that in these Indian diamonds, the surface energy controls the external morphology[2]. Could the curved forms be caused by abrasion (which is connected with surface energy)? If so, how can the faces still remain so lustrous?

A thin film of oil invariably forms on diamond surface. Half a century ago, Raman was convinced that unsatisfied dangling bonds on the surface attracted the hydrocarbons. By cleaving a diamond in vacuum and studying the reflection characteristics, an idea of the rate of growth of the film was obtained. Diamond surfaces and their dangling bonds are still worthy of study using modern techniques.

Diamond is said to belong to the highest holohedral centro-symmetric class; and yet many specimens exhibit hemihedry (acentricity). An extensive examination of Indian diamonds by Raman and myself established that a majority of these were acentric. Many optical and spectroscopic properties of diamond were explained by Raman as due to the mixing of centric and acentric structures (which he felt arose due to an intrinsic property of the carbon atom). [Raman C V, *Proc Indian Acad Sci*, **24A** (1946) 1]. It is now known that these effects are probably due to impurities (B, N, etc) which lower the holohedral symmetry at the microscopic level. Can these trace impurities alter the macroscopic symmetry and hence the crystal form itself?

Most diamond plates exhibit strain birefringence. This reduces the measured Faraday rotation, making it difficult to derive the true magneto-optic constant. Using the concept of the Poincaré representation of polarized light, a neat method was developed to calculate the real rotation[3].

(2) Studies on Optics and on the Effect of Pressure on Physical Properties

The revival of the Poincaré sphere concept played a crucial role in the

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development of optics in India at that time (G N Ramachandran, V Chandrasekharan, S Pancharatnam). New theorems were discovered in magneto-optics, novel designs of optical instruments ensued and new techniques of measuring photo-elastic constants were evolved. Classical papers on the Generalised Theory of Interference, written much before the discovery of lasers, led to the understanding of partial coherence and partial polarization[4].

A series of discoveries on the effect of pressure on physical properties followed: (a) uniaxial stress, like a magnetic field, splits the dispersion frequency; (b) natural birefringence and its dispersion with wavelength are also caused by the splitting of the dispersion frequency by the anisotropic distribution of the ions[5]; (c) metals exhibit photo-elasticity and the major contribution to this effect is by the free electron motion in an anisotropic lattice; (d) stress profoundly affects optical rotation and it can even induce optical activity in a certain class of non-optically active crystals[6]; (e) pressure can induce liquid crystallinity[7]; and (f) even a solid-solid transformation can show a critical point (SmS isostructural transition Cr Pt 825°C 10.5 kbar)[8].

(3) Optical and X-ray Effects

The wavelength of X-rays is more than a thousand times shorter than that of light. Can effects seen in optics be observed in the X-ray region and vice-versa? (a) "Optical activity" in the X-ray region was detected in cinnabar and quartz (0.1-1% of that in the visible region and in the same direction)[9]. (b) The Faraday effect in X-rays was not observed. (c) "Optical activity" was predicted for polarized neutrons transmitted along the axis of helimagnetic structures like didymium and holmium and experimentally verified in Brookhaven a few years later[10]. (d) The violation of Friedel's law and the Borrman effect are important X-ray effects arising because of multiple reflections in absorbing crystals. Both these could be observed in light in multilayer films (each layer consisting of unequal transparent and absorbing material)[11]. Optical Borrman effect could not be detected (in twinned iridiscent $KClO_3$). The best success in this direction was achieved when my student, Rajaram Nityananda (quite independent of me), predicted that the Borrman effect must be observable in a class of absorbing liquid crystals. This was experimentally verified by the Raman Research Institute Liquid Crystal Group.

(4) Anomalous Scattering of X-rays and Neutrons

My incursions into anomalous scattering of X-rays also came through the interest in the optics of absorbing crystals. Friedel's law violation arises due to an inherent phase change by the absorbing atom (f''). Bijvoet, in his classic paper of 1949, suggested that this can be used not only to determine the absolute configuration of structures but also to phase reflections. In his second classic of 1951 on strychnine sulphate-selenate, he suggested that by combining the isomorphous and his anomalous techniques, the phase problem can be solved without ambiguity. When there is an isomorphous replacement, the scattering power of the replaced atom changes. Since near the absorption edge the scattering power also changes (by f'), the thought occurred to me (1952) that a change in incident wavelength will achieve what isomorphous replacement does with the advantage that the "isomorphism" is perfect[9]. Hence by comparing the effects of f'' and f' at many wavelengths, one can solve the phase problem completely. The consequent details were worked out. This idea seems to have found a revival with the coming of the intense tunable synchrotron sources[11,12].

The suggestion of using neutron anomalous scattering for phasing very large structures made in 1965 has also had a fair success. Here again, one has to wait for an improvement in the neutron source intensity for the method to be universally applied[11].

The f'' and f' effects are really methods of labelling absorbing atoms. Hence, anomalous scattering techniques have been suggested for solving many crystallographic problems: polarization vectors; static displacement; and modulated structures. Our method of determining partial structure factors of binary liquids is regularly used for liquid alloys. It has also been applied by us to electron scattering, to explain the resistivity anomaly in caesium liquid at high pressures wherein some atoms have suffered "electron collapse"[12].

(5) Are Ions Compressible?

From among the possible coordination polyhedra, the Platonic solid—the icosahedron—was omitted by Linus Pauling (probably because of its pentagonal symmetry). Since there was no *à priori* reason for this omission, a systematic study was made of the coordination in compounds with highly polarizable ions. The oxygen coordination around Ba ion varied in different crystals from 6 to 12 and it was pleasing to find that in $Ba(ClO_4)$, $3H_2O$, the polyhedron is actually a perfect icosahedron[13].

These studies provoked the question: Can an ion be considered to be "soft", characterized by (i) a radius and (ii) a compressibility? When this was worked out using the Born theories, an important result followed. These two characteristic parameters of an ion can be used for that ion in *any* other crystal. The success of such an approach has been much beyond expectation[14]. Amongst other things, it explains the crystal structures of the 20 alkali halides, a problem that remained unsolved for several decades; one can calculate the lattice spacings, crystal structures, compressibilities and thermal expansions of a series of simple and complex crystals, as also the values of the temperatures and pressures at which they transform. It gives a plausible explanation for the semiconductor-metal transition of SmS, SmSe and SmTe[15]; it estimates the interionic distances in ionic melts.

(6) Applied Research

An interdisciplinary group gathered round me, and we made excursions into many fields of applied materials research. Some problems tackled with fair success were: the development and manufacture of FRP radomes to protect weather radar stations from cyclones; large sweep FRP fan blades for thermal power stations; big microwave dishes, porous FRP tubes for desalination; filament winding machines; high strength organic fibres for reinforcements; high silica fibres for insulation; electrocomposites for self-lubricating bearings and wear resistant surfaces; metal forming machines for spark erosion and electrochemical milling; stress measurement, stress relief, stress corrosion cracking, etc. [Valluri S R & Rajagopalan S R, *Bull Mater Sci*, **5** (1983) 373-80]. I shall not discuss the interplay of basic and applied research which made this exercise truly worthwhile.

Much of the work described cursorily in this account was done along with my gifted students and colleagues, many of whom in later years have distinguished themselves. To K Venkatesan, M A Viswamitra, N V Mani, H Manohar, A K Singh, S R Rajagopalan, N Balasubramanian, G R Ranganath, Rajaram Nityananda, T G Ramesh, Ramesh Narayan, R V Ramani, A V Ramani, Indira Rajagopalan and many others I record my grateful thanks for the privilege of being associated with them.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

U R Rao

Rao obtained his PhD in 1960 from Physical Research Laboratory (PRL), Ahmedabad in the field of cosmic rays under late Prof. Vikram Sarabhai. He joined the Massachusetts Institute of Technology (MIT) as a post-doctoral research fellow in 1961, where he worked on cosmic ray modulation and in the investigation of solar wind properties. In 1963, he joined the then Southwest Centre for Advanced Studies, Dallas, where he continued his cosmic ray investigations. He was the principal investigator for cosmic ray experiments which were successfully flown on Pioneers 6, 7, 8 and 9 Deep Space Probes and Explorer 34 and 41 satellites. The results of his experiments have provided a completely new insight into interplanetary physics.

After rejoining PRL in 1966, he initiated a new programme of research in the field of X-ray and gamma ray astronomy using balloon-borne, rocket-borne and satellite payloads. The X-ray payload fabricated by his group was also successfully flown on the first Indian satellite, 'Aryabhata'.

Rao has made a major contribution to our understanding of the cosmic ray time variations and in particular to that of diurnal and semi-diurnal variations of galactic cosmic rays. Employing sophisticated models of geo-magnetic field, he proposed a new concept of "asymptotic cones of acceptance", which is now used universally in studies on cosmic ray variations. In order to extend these studies to understand the micro-structure of interplanetary field, he and his colleagues designed special experiments flown on Pioneer series of Deep Space Probes and Explorer satellites. His work led to the formulation of a unified model based on convection and diffusion to explain all cosmic ray variations of both galactic and solar origin. Cosmic ray anisotropies, particularly solar flare anisotropies, observed on different spacecraft located at different heliodistances were used extensively to understand the nature of the interplanetary field, the extent and properties of corotating structures on the sun, the nature of the corotating shock fronts, intense cosmic ray storms and their behaviour, thus leading to a clear understanding of the interplanetary medium as a whole.

Another major contribution of Rao has been in the establishment of the continuous nature of the solar wind and its properties using Mariner 2 observations. He was able to establish, for the first time, the significant correlation of solar wind parameters with geomagnetic disturbances observed on the earth, thus establishing the dynamic interaction of solar wind with the earth's atmosphere.

In the field of high energy astronomy, Rao and his colleagues have investigated

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the detailed properties of both background and discrete X-ray and gamma ray sources using balloon-borne, rocket-borne and satellite-borne instrumentation. Detailed spectral properties of Sco X-1, Cyg X-1, Her X-1, Cen X-1 and Cen X-2 sources, including the establishment of correlation between optical and X-ray emissions of Sco X-1, the influence of celestial X-ray sources as a source of ionization for the lower ionosphere, discovery of periodicities and flare type enhancements in both optical and X-ray emissions, discovery of a new flare type star near cirius using optical observations, the establishment of a unique spectrum for the cosmic background gamma ray emission, are some of the major contributions made by Rao and his group in the areas of high energy astronomy.

Rao has been responsible for the establishment of satellite technology in the country. Under his guidance, the first Indian satellite 'Aryabhata' was designed, fabricated and launched from USSR Cosmodrome in 1975. Following this, Rao and his team were responsible for the successful launch of two experimental remote sensing satellites, Bhaskara-I in 1979 and Bhaskara-II in 1981 and the first experimental geostationary communication satellite APPLE in June 1981. Under his guidance, two Rohini satellites were launched successfully using SLV-3. APPLE was used continuously for over 27 months to carry out telecommunication digital experiments.

Rao, as Chairman, INSAT-I Board, provided overall guidance for the INSAT Project and was also responsible for carrying out all technical and other reviews of the Project. INSAT-I system is the first operational system for providing communication, TV and meteorological services, through geostationary multipurpose communication satellites. The indigenous second generation INSAT, namely INSAT-2 system, has also been designed under his guidance.

IRS, the first semi-operational remote sensing satellite weighing 950 kg, a highly complex three-axis stabilized polar orbiting satellite capable of providing state of art imageries with a resolution of 30-35 metres, has been designed and is now under fabrication under Rao's overall guidance. IRS-I is expected to be launched in mid-1986. Likewise, SROSS series of satellites weighing 150 kg for launch on ASLV are also being designed and fabricated under his overall guidance. The first ASLV/SROSS launch is expected to take place during 1985.

Rao took charge as Chairman, Space Commission and Secretary, Department of Space, on 1 October 1984.

Rao's research interest varies over a wide range of subjects, such as cosmic rays, interplanetary physics, X-ray and gamma ray astronomy, solar physics and satellite technology. He has published over 150 scientific and technical papers.

Rao was elected a Fellow of the Indian Academy of Sciences in 1968 and a Fellow of the National Academy of Sciences in 1980. he has been and is a member of a number of national and international scientific bodies.

For his work on Pioneers 6, 7, 8 and 9 deep space probes and Explorer 34 and 41 satellites, he was awarded the 'Group Achievement Award' by NASA in 1973. For his work on Aryabhata, Rao was awarded a medal of honour by the USSR Academy of Sciences in 1975. He was the recipient of Karnataka State Award on the Rajyotsava Day in 1985. For his work in the field of space physics, he was awarded 'Hari Om Ashram Prerit Vikram Sarabhai Research Award' for 1975. For his contributions in the field of engineering sciences, he was awarded 'Shanti Swarup Bhatnagar Memorial Award' for 1975. He was awarded the 'National Design Award' by the Institution of Engineers (India) in 1980. Rao was awarded the VASVIK Research Award for 1980 in the field of electronic sciences and technology. He was awarded the Karnataka Rajyotsava Award in 1983.

Rao is a recipient of honorary doctorate from the University of Mysore, Agricultural University, Rahuri, Calcutta University and Mangalore University.

Rao was awarded 'Padma Bhushan' in 1976.

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N K Saha

My early work (1934-36) was in the field of electron theory of solid metals[1] based on the then developed Bloch-Nordheim theory. The theory of change of electrical resistance of metals with pressure was worked out as an application of Nordheim's rigid ionic model[2]. The pressure coefficient of electrical resistance was calculated for a large number of metals at 0°C and − 183°C. The results obtained were generally in good agreement (except for the alkali metals) with the experimental results of Bridgeman up to a high pressure of 7000 kg/cm^2.

From the end of 1936, I was engaged in experimental work in the field of nuclear physics in the laboratories of the (now) Max Planck Institute of Physics, Heidelberg, West Germany. I undertook a comprehensive study[3] of the excitation functions of (α, p), (α, n) and (α, γ) reactions in ^{19}F nucleus with 5 MeV α-particles. Resonance and ground energy levels of the common compound nucleus ^{23}Na formed in the three reactions were identified experimentally and depicted schematically. This was perhaps one of the earliest works designed to experimentally verify Bohr's 'liquid drop model' of the atomic nucleus published only quite recently at that time. This was followed by measurement of relative cross-sections of (n,p) reactions[4] in a series of light nuclei by the 'activation method'. A short interpretation[6] of the β-spectrum of radioactive arsenic was given.

In those early days of experimental nuclear physics in India, work was greatly handicapped due to lack of indigenous nuclear instrumentation. My collaborators and I in the University of Delhi developed various types of nuclear radiation measuring instruments[5] of research standard, and stabilized high voltage devices in various ranges based on the corona principle, which partially relieved the situation. Among other things, a new instrument of some significance that we successfully developed was the 'spark counter'[7,8]. Here, the spark breakdown in the corona space between two (wire-plate) electrodes by ionizing α-particles was utilized to detect the high energy particles. As is well known, this principle was later used widely elsewhere in the famous 'spark chamber' for visualizing and photographically recording the complex high energy particle phenomena in elementary particle physics. A number of elegant applications of the spark counter were also made by us.

Apart from the dearth of advanced nuclear technology in those days, very few universities in India imparted systematic teaching in nuclear physics at the post-graduate level. Even if something on the theoretical side of nuclear physics was

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taught at some places, the experimental side was almost completely neglected due primarily to the lack of proper equipment.

Even in the face of all these difficulties, the importance of developing experimental nuclear physics in the country was realized, both for its fundamental academic contribution and its wide application in industry, medicine and atomic energy generation. Consequently, serious efforts were made in this direction at various research centres in the country. In Delhi University, a dedicated band of workers in this subject emerged who acted as my collaborators and an important programme of investigation was undertaken.

The age of sophisticated nuclear spectroscopic technology also came to India, and we were not lagging behind and closely followed the development.

As a result, in later years (after 1960), our interest in the field of nuclear physics widened. I and my collaborators undertook systematic precision measurements on the following three lines:

I. Study of $\gamma\gamma(\theta)$, the directional correlation of $\gamma\gamma$-cascades in the decay of a series of medium heavy nuclei like ^{115}Cd, ^{160}Dy, ^{129}I (ref. 9), ^{187}W, ^{123,125}Te (ref. 10, 11), ^{144}Pr, ^{82}Br (36 hr), ...etc.

II. Half life measurement of some excited levels in ^{59}Co (ref. 12), ^{141}Pr, ^{233}Pa (ref. 13), ^{227}Ac, ^{237}Np, ... etc.

III. High resolution measurement of γ-ray spectra and energy levels in most of the above cases, especially in the decay of ^{59}Fe to the levels of ^{59}Co (ref. 14).

High resolution Ge-Li and NaI(T1) detectors with elaborate fast-slow coincidence spectrometer assembly and 'Nuclear Data' multichannel pulse height analyser were used in the measurements. Extreme care was taken to obtain a good geometry and to correct adequately the $\gamma\gamma(\theta)$ measurements for Compton contribution and interference from any neighbouring cascades. The results in many cases revealed surprising agreement with the theoretical calculations, where previous measurements had shown considerable disagreement.

All these works provided valuable basic nuclear spectroscopic data for a wide range of nuclei, such as the spin and parity of the states, and added considerably to our knowledge of nuclear decay schemes. Limitations of existing nuclear coupling schemes giving calculated nuclear levels were also examined in the light of the experimental results. Special mention may be made of the comprehensive measurements of ^{129}m Te-decays to the excited levels of ^{129}T, and of ^{59}Fe decays to ^{59}Co.

As a logical extension of the above investigations, a technique was developed for a new line of work bordering on the nuclear and solid state physics, in which the familiar angular correlation measurements could be made to provide information on interactions in the solid state of matter.

IV. Measurement of $\alpha\gamma(\theta)^*$, the perturbed angular correlation (PAC) in α-γ decays in heavy nuclei[15,16].

This was successfully carried out in a polycrystalline ^{241}Am sample with 5.486 MeV α-decay to 59.6 keV level of ^{237}Np with 66.7 ns γ-decay half-life.

The thickness of the source prepared was estimated to be less than 1 μm. It is presumed that the high energy (100 keV) recoils stop within the source, as their range in americium is of the order of 100 Å. This, coupled with the long life of the intermediate state of ^{237}Np γ-decay, would give ample opportunity for the perturbation of the $\alpha\gamma$-correlation in the external atomic fields at the recoiling nucleus to occur.

The two detectors [α-particles in a silicon surface-barrier detector and γ-rays in a movable NaI (TI) time differential coincidence system] with fast leading-edge pick off timing and a time-to-pulse-height converter were used. The data were recorded on a Nuclear Data 2048-channel analyser.

As a result of the investigation we could report: (i) the time-dependent behaviour of the interaction, (ii) the time integrated attenuation coefficients, and (iii) the spin-relaxation time of the 5f-electron shell in neptunium. The results strongly suggest that the time-dependent character of the angular correlation is carried primarily by the magnetic interaction of the unfilled 5f-electron shell of ^{237}Np ion with the magnetic moment of the nucleus and secondarily by the electron excitation of the Np atom.

As a future programme of work, investigations of $\alpha\gamma(\theta)$* on these lines will be extended by my collaborators (on my retirement) to a series of transuranium heavy radionuclides where many such cases of perturbed angular correlation are expected to occur, so that the mystery of the solid state interactions in the polycrystalline materials in them could be revealed. This programme may involve considerable difficulties by way of preparation of suitable polycrystalline thin steady sources and other technical problems. But I believe that the efforts would be sufficiently rewarding, if the programme could be carried out successfully.

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Satya Prakash

My research career started with the establishment of a cosmic ray neutron monitor at Kodaikanal for the study of the effect of solar wind and interplanetary magnetic field on the cosmic ray particles, under the guidance of Prof. V A Sarabhai. This was the first neutron monitor established near the geomagnetic equator and yielded very valuable results[1]. Using an all metal gas purification system[2], developed at the Physical Research Laboratory (PRL), Ahmedabad, the BF_3 filled proportional counters were prepared for this neutron monitor. This work was continued at California Institute of Technology with the aim to develop a Neher type ion chamber using BF_3 and $B(CH_3)_3$ gas for balloon-borne studies on cosmic radiation.

With the establishment of the rocket launching station near the geomagnetic equator at Thumba (TERLS), my interest shifted to the study of upper atmosphere using space-borne experiments. The earth's ionosphere is a unique and ideal plasma laboratory provided by nature for the study of various plasma processes, which are difficult to study in the laboratory. Three different plasma conditions are realized in D, E and F regions of the ionosphere. In the height region around 105 km, the electrons alone are magnetized, while in the lower region, both ions and electrons are unmagnetized; in the higher region, both are magnetized. Thus, one can study irregularities produced in three different plasma regimes. Under certain ambient conditions, the plasma in these regions becomes unstable and supports a host of irregularities. The study of these irregularities is important not only for understanding the basic plasma processes responsible for their generation but also for understanding the various phenomena occurring in the upper atmosphere. For the study of plasma processes, the equatorial region has many advantages over the auroral region. Since the geomagnetic field is horizontal at the equator, the medium can be considered as stratified, the direction of electric field is predictable, and there are no complications due to particle precipitation. Of course, plasma processes produced through particle precipitation cannot be studied at the geomagnetic equator.

For these studies, payloads with many novel ideas were developed and flown onboard rockets from Thumba. For the study of plasma density irregularities, a Langmuir probe with high frequency response and high signal to noise ratio was developed[3]. A spin symmetric resonance probe system[4], which forces the signals to penetrate deep into the plasma, was developed which gave very sharp resonances at the upper hybrid frequency

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(f_T) and thereby could be used to determine electron densities with accuracies better than 1%, when $f_T > 2$ MHz. The absolute density derived with the resonance probe and the current derived from the proton precession magnetometer of Dr T S G Sastry were used to determine the relative drift velocity of ions and electrons, which is an important parameter for the study. Lyman alpha photometers were developed and flown to measure the intensity of solar radiation and thereby determine the structures in the neutral density in the mesosphere[5]. The calibration facilities, such as light sources and UV monochromator, were developed and this facility has now developed into a full-fledged UV laboratory for the study of atomic and molecular cross-sections of interest in atmospheric sciences and astrophysics. A VHF backscatter radar operating at 44.95 MHz was developed and established at Thumba[6]. This was one of the first two radars at the geomagnetic equator. This radar was used to study the spatial and temporal variations of the irregularities and their relationship with ambient electric fields and other relevant parameters. Recently, electric field probes[7], which could measure both horizontal and vertical electric fields, were developed and flown from Thumba for the study of fields associated with the plasma density irregularities. This was the first time that at least one of the components of the electric field (vertical in the present case) could be measured without interruptions. Studies with the above space-borne probes and the ground-based VHF radar have for the first time given the scale size spectrum of irregularities, their relationship with the gradient in electron density, relative velocity between ions and electrons and the amplitude and direction of the ambient large scale electric field. This has led to the study of gradient drift instability[7,8], two-stream ion wave instability[7,9], irregularities due to neutral turbulence[10,11], large scale irregularities due to gravity waves[12], and the metallic ions[11]. Rocket-induced irregularities with frequencies close to ion plasma frequency were also observed near the rocket apogee. The results have been reviewed by Satya Prakash and Pandey[11]. Another outstanding problem in the equatorial region is the dynamics of the F-region and the plasma instability mechanisms operating in this region. These mechanisms give rise to plasma density irregularities with scale sizes as large as thousands of kilometres along the geomagnetic field lines. In the plane perpendicular to the geomagnetic field, the scale sizes of these irregularities vary from a few hundred kilometres to as small as a few centimetres. A proper study of these irregularities requires studies with rocket and satellite-borne payloads and ground-based experiments, such as ionosonde, VHF backscatter radar and using various optical techniques.

Recently, Indian rockets with an apogee of 350 km have become avilable and these have been used to study the plasma processes in the F-region. On one of our rocket experiments, the irregularities produced through EXB instability mechanism could be identified for the first time[13]. Irregularities due to drift waves were also observed and various properties of these irregularities were studied in detail. The study of plasma instability mechanisms in the F-region is at a preliminary stage and work will be continued using high altitude rockets.

Payloads of retarding potential analyzer and the ultraviolet ion chambers were developed and flown on the first Indian satellite, Aryabhatta, during 1975 to study the dynamics of the F-region. Unfortunately, the experiment did not receive power. Payloads of Langmuir probe and electric field probes will be flown on the Indian satellite SROSS-III, which will be launched from SHAR range during 1987 to study the dynamics of the F-region and various plasma instability mechanisms operating there. A few rocket experiments will be carried out simultaneously to study the vertical structure of various plasma parameters. These experiments, together with ground-based experiments, such as VHF radar for the spatial and temporal distribution of 3-m scale size irregularities, satellite scintillation for the spectrum and motion of large scale irregularities, Febry Perrot interferometer for neutral winds and temperature and maps of 6300Å airglow emission, are expected to give very valuable complementary results.

A three-dimensional model for the interaction of gravity waves with the ionospheric E-region plasma was developed[14] to study currents, electric field and transport of ionization produced through this interaction. It was also shown that the wind shears in the gravity waves would give rise to the formation of ionization layers in the equatorial E-region, which was earlier believed to be not possible. It was shown theoretically that the gravity waves can generate oscillatory electric fields, which can be transmitted from the E- to the F-region and vice versa, if the wavefront of the gravity waves is parallel to the geomagnetic field lines in the region where the Pederson conductivity is maximum[15]. These fields are of great relevance in the formation of equatorial spread F. This disproves the results of earlier studies where it was shown that the oscillatory winds in the E-region will not give rise to fields which can be transmitted to the F-region. Recently, a theoretical model based on production and loss of metallic ions, transport of electric field and gravity wave winds has been developed to explain the formation of ionization layers during the daytime in the E-region. In future, we plan to continue the study of the growth of plasma density irregularities in the equatorial E- and F-region due to various plasma instability mechanisms.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

K P Sinha

Starting my research career in chemical physics of solids, I made a natural entry into condensed matter physics, which I have pursued for the last three decades. In recent years, I have contributed significantly to the emerging area of superstrong gravity which operates in matter at extreme densities. These researches, resulting in over 200 papers, have settled some issues and opened up new avenues of explorations in India and other countries. The highlights of the significant contributions, made singly and jointly, are adumbrated below.

Chemical Physics of Solids

Using the concept of phonon-lattice interaction, a precise formulation of the reaction mechanism and the temperature regime at which solids enter into interaction was developed[1]. This study was extended to the origin of structural phase transitions in spinel-like systems wherein I was associated with the discovery and the first theoretical treatment of cooperative Jahn-Teller effect (CJTE)[2]. These researches triggered off vigorous activity in India and various laboratories in Japan, USA, UK, Europe and USSR. This led to the recognition of the importance of pseudo John-Teller effect in the origin of ferroelectricity and the softening of phonon modes[3]. The papers published provided a new microscopic basis of lattice distortion and instability of vibrational modes at a critical concentration of J T ions or at a critical temperature.

Interactions in Magnetic Solids[4–6]

In this area, very significant and substantial contributions have been made to almost all possible interactions in magnetic solids. These involve the study of indirect spin coupling between paramagnetic ions which depends on the subtle effects of spatial correlations and spin-dependent polarization of the electrons of the diamagnetic ions to explain the magnetic ordering in a large number of magnetic solids[6]. This was followed by first principle formulation of interaction mechanisms among various elementary excitations in magnetic systems, e.g. magnons, phonons, photons, neutrons and conduction electrons. These mechanisms and the study of the associated kinetic phenomena—relaxation, heat transport and scattering cross-sections—have greatly contributed to an understanding of a large number of magnetic systems[6]. A general expression for the Mössbauer line shape in the presence of radio frequency field was developed, which gave new transition lines and explained experimental data on combined Mössbauer and NMR study on some systems.

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Semiconductors, Metals and Alloys[7-10]

Our theory of carrier mobility in some polar semiconductors provided an answer to a long-standing problem[7]. That resistance minimum would show up in alloys having impurities with no localized moments was predicted independently by us in India[8] and by Kim in USA. In this mechanism, conduction electrons are scattered with orbital excitation along with spin-flip of impurity electrons. These have been confirmed in titanium-containing alloys. The occurrence of giant magnetic moments of the order of 12-14 Bohr magnetons in alloys of Fe and Co dissolved in 4d-5d series matrix had been a serious theoretical challenge for some time. This was resolved by invoking combined effects of state mixing and exchange interactions[9]. The results are in remarkable agreement with experimental data. Non-radiative processes in electronic and excitonic transitions in semiconductors of great practical importance were developed[10].

Electronic Phase Transition[11(a)]

A new theory of insulator-metal transition was developed. The model envisaged involves the existence of two types of electronic states. One is extremely localized (non-conducting) and the other fairly extended (band type). These states are separated by a gap. Initially, the localized states are fully occupied, while the band type states that lie above are empty. At a finite temperature, some electron-hole pair excitations are thermally produced. Since the electrons are strongly coupled to the lattice, this interaction leads to a 'closing-in' of the surrounding lattice. Thus, a positive internal strain is generated which lowers the hole energy parametrically. This favours further electron-hole pair excitation, which, in turn, produces more strain, thus completing the feedback loop. A collapse of the energy gap, which is now a function of such pairs, occurs at a critical temperature. The estimated temperature and volume change are in accord with experimental results.

Superconductivity and cuperfluidity[11,13]

With a view to realizing high transition temperature (T_c) superconductivity, we turned our attention to some novel electronic mechanisms and conditions. Our mechanisms of pairing under non-equilibrium conditions which involve two Bose fields, e.g. phonons, photons or excitons, in scattering and mixing processes and depend on the density of the boson field have had considerable impact[11(b)]. These papers, recognized as the first suggestion of non-equilibrium mechanism, had led to intensive theoretical and experimental work in several centres. In subsequent work, we studied the enhancement of superconductivity owing to electron-phonon vertex renormalization by an impressed radiation field and the possibility of (triplet) *p*-wave pairing under these conditions[12]. With the discovery of magnetic superconductors, we developed new mechanisms of the coexistence of superconductivity and long range magnetic order and anomalous behaviour of the second critical field in some antiferromagnetic superconductors[13].

Following our work on electron-hole recombination and excitonic transitions[10], we studied electron hole and exciton pairing to see the possibility of their superfluid behaviour. This led to a very important ramification which involved the pairing of particles and antiparticles to give a non-empty superfluid vacuum state pervading the universe. This completely covariant sub-quantal level of reality is finding application in the interpretation of some recent experiments connected with quantum theory of measurement.

Gravity at Extreme Densities

In strong analogy with phase transitions in condensed matter wherein some macroscopic order parameters appear and coupling constants change radically and mediating bosons become massive, I along with coworkers sought radical modification in the laws of gravity at extreme densities. In the last 10 years and in a series of papers (nearly 30)[14], it was demonstrated that beyond a critical matter density 10^{17}g cm^{-3} (which may obtain inside hadrons, extremely dense stars or in the early stage of the universe) Newton-Einstein laws get modified such that the coupling constant becomes superstrong and the symmetry breaking leads to a large parameter (in this case a very large cosmological constant Λ_f) and the spin-two gluons become massive. This leads to extremely short range gravitational interaction and owing to the presence of Λ_f, antigravity effects besides the usual attractive interaction. These effects lead to very important results—from the stability of elementary particles to the prevention of the gravitational singularity. There are important consequences on fundamental physics, including unification with other forces, for example, weak, electromagnetic and strong interactions[15]. These have led to considerable activity in several countries in this emerging area.

Future Plan of Work

I intend to continue my deep interests in condensed matter physics and gravity at extreme density. However, I shall focus my attention on the following specific problems in the next few years.

Magnetic superconductors: These involve both phonons and magnons with which conduction electrons interact. Also, these Bose fields interact among themselves. A detailed study of these systems is likely to reveal interesting quantum interference effects.

Study of Jahn-Teller polarons: Our recent study of some systems has shown it to be an extremely promising new field with the possibility of phonon amplification and generation of coherent phonons.

The nature of gravitation in the early universe: It has been recently shown by us that in the early stages, when the matter density and temperature were extremely high, the gravitational interaction changed sign (becoming repulsive from attractive) above a critical temperature. This may be the cause of big bang. This, if further substantiated by detailed work on quantum gravity, will save the universe from singularity.

As in the past, I shall continue my team work with young students, collaboration with colleaugues in India and abroad and nurture research in foundations of theoretical studies.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M S Sinha

Sinha's research activities, in its earliest phase, were carried out at the Bose Institute, Calcutta, under Prof D M Bose and at the Indian Institute of Science, Bangalore, under Prof H J Bhabha, where he constructed a completely mechanized counter-controlled cloud chamber for the first time in India and studied the nature of penetrating showers and scattering of mu-mesons produced in lead. The results were incorporated in his dissertation for the DSc degree of the Calcutta University (1946). He later made a thorough study of the various properties and nature of interactions of the muon component of cosmic rays.

Along with N N Biswas, Sinha measured the mean life of muons in low, medium and high Z elements, and showed that negative muons are partially captured in medium Z elements, completely in high Z elements and the natural mean life is the same for both kinds in low Z element. He and N C Das devised a new method for determining the nuclear radii of different elements by studying the nuclear interactions of the nuclear active component of the cosmic rays in a multiplate cloud chamber. He studied with S N Sengupta the asymmetrical production of decay electrons from stopped muons in copper in the forward and backward hemispheres of the parent muon. The up-down ratio of electrons emitted from muons stopped in a multiplate cloud chamber was found to be 1.17 ± 0.05, as expected from the non-conservation of parity in muon decay. Both these experiments were carried out at the High Altitude Research Station of Bose Institute at Darjeeling. At Calcutta, exhaustive measurement of the low energy spectrum of cosmic ray muons and electrons was made with Nilima Mishra, data for which were not available earlier.

Sinha carried out, with N Chaudhury, an experiment on the electromagnetic interaction of muons direct-pair and knock-on electron production at an underground research station at Maithon (148 m).

From 1961 onwards, Sinha's research activities shifted to Durgapur under the auspices of DAE research projects. A detailed study of the variation of dpp cross-section of muons with Z was undertaken along with A K Das by running two multiplate square cloud chambers simultaneously under large thicknesses of lead. In 1965, a new project was taken up for constructing a double magnet cosmic ray spectrograph at Durgapur. The spectrograph was operated successfully for the first time in India in 1969 and valuable results were obtained on the momentum spectrum and charge ratio of muons with B C Nandi. The spectrograph was then run with a square cloud chamber

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placed below it filled first with helium and then with argon. The purpose was to measure the variation of ionization loss of muons in these gases with muon momentum. The experiment was conducted along with P S Basu by photographing delay expansion tracks of muons whose momenta were measured in the spectrograph placed above. The results showed good agreement with Sternheimer's theory in the highly relativistic region.

Sinha was awarded a Post-Doctoral Fellowship to work with the cosmic ray research group of M.I.T., Cambridge, under Prof. Bruno Rossi for one year (1950-51). He was a visiting scientist at Durham University for working on cosmic ray spectrograph with Prof. A W Wolfendale for three months (1965), and attended four international conferences on cosmic-ray physics—Jaipur (1963), Budapest (1969), Denver (1973) and Munich (1975).

Sinha has published about 40 original papers.

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M S Sodha

Sodha has opened up many avenues of research in pure and applied physics in India. He is a pioneer researcher in the areas of optics (instruments, fibre and atmospheric), transport phenomena in plasmas and semiconductors, interaction of electromagnetic fields with plasmas and utilization of solar energy.

In optics, Sodha is best known for his work on geometrical and physical optics of graded refractive index optical wave guides; Sodha's approach has led to closed form solutions for Gaussian beams. He, together with Prof. Ghatak, has authored the first book[1] in this contemporary area; the book has been translated into Russian and Chinese. His work on image formation in stratified media and its application to mirage and looming is also very interesting.

Sodha has worked extensively on transport phenomena in plasmas and semiconductors. His derivation[2] of the collision integral for the case of nonequilibrium degenerate semiconductors and consequent derivation of energy distribution of carriers for high electric fields is an original and significant work. Sodha's conclusions[3] that inhomogeneities in carrier density and temperature can lead to nonequilibrium energy distribution of carriers is a significant contribution. He has put the physics of colloidal plasmas (solid particles suspended in a gas) on a firm basis and applied it to MHD power generation and reduction of electron density in the plasma sheath around a re-entering hypersonic vehicle; the work[4] is pioneering in nature. Sodha and his group have been significant contributors to the MHD effort in the country besides BARC and BHEL (which have been designated to implement the national programme).

Sodha's group is probably the most productive group in the field of self-focusing of laser beams in gaseous and solid state plasmas and the effect of self-focusing on parametric processes; a book[5] and a review[6] indicate the scope of this work. Sodha's approach leads to explicit solutions and very interesting conclusions for the case of saturating non-linearities and overdense plasmas[7]. He has also reconciled[8] the various approaches to the theoretical study of self-focusing and defined their limits of applicability.

Sodha's work on interaction of electromagnetic waves with collisional plasmas is characterized by simultaneous use of Boltzmann's transfer equation and Maxwell's equations. The problems investigated include linear steady state propagation, nonlinear propagation, harmonic generation and combination frequencies[9], demodulation and cross-modulation. Use of acoustic waves[10] and time varying magnetic fields[11] has been proposed and analysed as means of

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communicating (by electromagnetic waves) through overdense plasmas (with special reference to plasma sheaths around a hypersonic vehicle and rocket plumes).

Sodha's book[12] (coauthored with Srivastava) on microwave propagation in ferrites is a classic reference book.

Sodha's work on the utilization of solar energy is characterized by novel concepts, rigorous analysis, designs (based on the analysis and engineering principles), numerical modelling, experimental validation of the numerical models and cost-effective designs, based on the models.

One of the recent activities of Sodha and his group is computer aided design of buildings for thermal comfort with zero or minimum energy needed for heating/cooling; this effort, unique in the country, utilizes the concepts of solar passive architecture. Under a DNES project, buildings have been designed for Srinagar, Delhi and Jodhpur, representing wide climatic variation; the buildings are at different stages of construction and evaluation. In another project, supported by NEDA, UP, buildings at Chinhet (District Lucknow) and Nainital have been designed. This pioneering activity has the potential of attaining new heights of thermal comfort and energy conservation in buildings in India. Sodha and his group have proposed new concepts, rigorously analyzed existing concepts and proposed new methods for computer prediction of the thermal performance of buildings. A book[13] on 'Solar passive buildings: Science and design' by Sodha and his colleagues is the first to combine the scientific and design aspects in a quantitative manner. A computer programme for optimum use of insulation in a building has also been prepared.

Sodha and his group have proposed and developed the concept of an inexpensive multiple wick solar still, whose distillate production is 50% more than that of the conventional still; this still is under production in the industry. A book[14] on 'Solar distillation' authored by Sodha and his associates is the only text in this area.

Sodha has made extensive contributions to the field of solar hot water systems. The most notable contribution is the design and development of systems which prevent reverse flow during off-sunshine hours; the device is being used by the industry. A techno-economic numerical model to evaluate the optimum collector area and tank volume (to meet a specific demand pattern) for minimum cost has given interesting results. A report[15] on status of solar collector/hot water system testing and a computer controlled testing rig for solar collectors are significant achievements of Sodha and his colleagues.

Other contributions in solar energy utilization include numerical modelling and its validation for integrated collector/storage systems and solar crop drying; a book[16], a review[17] on mathematical models and a six-volume report[18] on solar crop drying for the World Bank are highlights of this work.

Sodha and his group have made extensive investigations on solar assisted biogas plants and established that a solar canopy over KVIC plants leads to acceptable levels of biogas production in the northern plains of India.

Sodha is one of the three editors of a series[19] entitled 'Reviews of Renewable

Energy Resources'; four volumes of the series have been published.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B V Sreekantan

The early phase of Sreekantan's research activity starting from 1948 coincided with the period when cosmic ray research world over underwent a transformation from being just an exploratory phase of understanding the nature and properties of the secondary and primary cosmic ray particles into one which ushered in on the one hand the field of high energy physics and elementary particle physics, and on the other became an important branch of astrophysics. This transformation was to a great extent a consequence of the exploitation of new developments in particle detector technology and the advent of sophisticated capabilities in electronics and computer sciences. In this broad context of development of cosmic ray research, the role of the Indian cosmic ray research groups, in particular that of the Tata Institute of Fundamental Research (TIFR) group, is not insignificant. Cosmic ray research effort at TIFR encompassed practically all aspects of the radiation-primary composition and spectrum, high energy interactions, muons, neutrinos, electrons, gamma rays, solar particles, modulation effects, origin theories, etc. In this overall effort of the TIFR cosmic ray group, which was one of the largest in the world, Sreekantan's involvement has been especially in the series of experiments that have been carried out over the past three decades in the deep underground levels at the Kolar Gold Fields (KGF), in the high altitude cosmic ray research station at Ooty and with balloons and rockets flown from Hyderabad, Thumba and Sriharikota in India. In all these investigations, which involved a large number of scientists, he has essentially been the group leader all through.

An important aspect of the TIFR effort that paid rich dividends was the very special effort that was placed in the earlier years in the indigenous development of a variety of particle detectors and associated electronics—almost in parallel and in some instances ahead of other groups in the world. It has to be emphasized that this development had to be made practically inhouse, since industrial support in the country was very little in the late 40s, 50s and 60s. Mention may be made in particular of the developmental efforts in the field of large area liquid and plastic scintillators, multiplate cloud chambers, total absorption spectrometers, large area triggered spark counters, neon flash tube assemblies, air Cerenkov counters, high pressure proportional counters for X-ray telescope, etc. The development of microsecond electronics in the late 40s and nano-second electronics in mid 50s, played an important role in the sophisticated experiments that were

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undertaken. These detectors were incorporated in the deep underground levels at KGF and also in the two extensive air shower arrays—one at Ooty and the other at KGF.

First Phase of Underground Experiments at KGF

Deep underground experiments for the measurement of the intensity and angular distribution of the penetrating components of cosmic radiation were first started in the Kolar Gold Mines by Sreekantan in 1951 and the results from this first series constituted the subject matter of his PhD thesis. These were followed by multiplate cloud chamber investigations on the interaction characteristics of mu-mesons[1,2]

The Second and Succeeding Phases of Experiments at KGF—Neutrino Experiments

The next phase of deep underground experiments at the KGF was started in 1960 with the objective of extending the intensity depth measurements to the largest possible depths in the mines.

The intensity depth measurements in the mines showed that at the largest depth of 9000 ft underground, no count was registered in the cosmic ray telescope in an operating period of 90 days. In two papers published in 1963, one in *Physics Letters* and other in *IL Nuovo Cimento*, the significance of this result from the point of view of (i) the feasibility of detecting cosmic ray neutrinos at such large depths using suitably designed experimental arrays, and (ii) setting up an upper limit on the life time of the proton were discussed. This was followed by concrete action and in less than a year's time large area neutrino telescopes were set up at a depth of 2300 m as a collaborative effort of TIFR, the Durham University and the Osaka City University groups. The first convincing visual record of neutrino interactions was presented at the International Conference on Cosmic Rays at London in August 1965. These investigations continued for several years and yielded important results on several aspects of neutrino interactions and high energy cosmic ray muons.

KGF Air Shower Array

Realizing the unique facilities available at different depths underground and the importance of studying the properties of extensive air showers of cosmic radiation associated with very high energy muons from the point of view of eliciting the collision characteristics of very high energy primary cosmic rays in the top layers of the atmosphere and the nature of the primary cosmic ray at very high energies, a large scale air shower array was set up at KGF in 1963. This is a unique installation with large area neon telescopes, scintillation counters and water Cerenkov counters at various depths underground operating in conjunction with a sophisticated air shower array comprising 73 scintillators spread over an area of 100 m radius at the surface of the mine. The results on the lateral distribution of muons of energy greater than 200 GeV, the spectrum of muons in the 10^{11}-10^{13} eV range obtained in this experiment after almost a decade's continuous experimentation, led to important conclusions on the composition of primary radiation around 10^{14} eV.

Multiplate Cloud Chamber Investigation on High Energy Interactions at Ooty

In the mountain station at Ooty, a series of investigations were started in 1956 to study the characteristics of ultra-high energy interactions using multiplate cloud chambers in the energy range above 10 GeV, which was the maximum available energy at the accelerators. A hybrid set-up consisting of an air Cerenkov counter, a multiplate cloud chamber and a total absorption spectrometer mounted one below the other, was made operational at Ooty in 1960. Important results on the differences in the characteristics of pion and proton interactions in the energy range 10-40 GeV were obtained just a little before the advent of the CERN 30 GeV proton accelerator.

Extensive Air Shower Experiments at Ooty

The Ooty extensive air shower array was set up in 1960. In the first few years, emphasis was on the study of the fluctuations and the correlations in the fluctuations of different components of air showers—electrons, muons and hadrons from the point of view of eliciting information on the characteristics of collisions and primary composition. In 1964, the most systematic investigation on the hadron component of air showers was started by introducing the total absorption spectrometer also into the array. Detailed studies on the time structure of hadrons using the total absorption spectrometer and extensive use of Monte Carlo simulation of the different parameters of the air showers led to several important results—one of the most important being the clearcut evidence for increase in the cross-section for the production of N-N pairs as a function of energy. The experiments showed that the content of nucleons and anti-nucleons among the secondaries could be as high as about 10% of the secondary particles produced in the collisions of energy greater than a few TeV. The results on the time structure of hadrons and their implications are discussed in series of papers[3,4].

In 1965, the very large multiplate cloud chamber at Ooty, the world's largest multiplate cloud chamber—2.5 × 1.5 × 1 m with 7 tons of iron inside in the form of multiplates—was incorporated into the Ooty air shower array as another hadron detector. There was a clear indication from this study that the characteristics of interactions do have to undergo a drastic change in the composition of secondary particles, multiplicity dependence of secondaries on energy and behaviour of transverse momentum distribution. While some of these results have been confirmed by later cosmic ray and accelerator experiments, others await confirmation by the experiments with the new generation of accelerators[5–7]

Search for Ultra-high Energy Gamma Rays ($>$ 100 GeV) from Pulsars

Soon after the discovery of the first radio pulsar, experiments were initiated in the Ooty Cosmic Ray Labortory to search for pulsed ultra-high energy gamma rays from pulsars employing the principle of the night air Cerenkov technique. Over the years, the areas as well as the number of searchlight mirrors mounted on individual electronically controlled orientation platforms that enable tracking of sources for several hours before and after meredian transit have been increased and currently the Ooty Ultra-High Energy Gamma Ray Telescope with a collecting area of 20 m^2 is the largest in the world. Observations over a period of five years have shown that the Crab Nebula and the Vela pulsar do occasionally give rise to ultra-high energy pulsed gamma ray emission and the source intensity in both fluctuates by a large factor. A summary of these extended observations was presented at the Gamma Ray Workshop held at the Royal Society, London, in November 1980[8,9].

Experiments in X-ray Astronomy

Realizing the special advantages of the equatorial latitude with low cosmic ray induced background of secondary photons in the upper layers of the atmosphere and the availability of some of the first X-ray sources like Sco X-1, Cyg X-1, Cy X-3, Tau X-1, etc. at high zenith angles at the time of meredian transit, a vigorous programme in hard X-ray astronomy using stratospheric balloons flown from Hyderabad was initiated as early as 1967 when very few international groups were working in this field. These early experiments provided valuable information relating to the spectra, time variations, bursting activity, pulsed fraction, etc. of many of the sources. Detection of sudden bursts in Sco X-1[10] and in Cyg X-1[10] and evidence for a sudden change in the level of intensity by almost a factor of the Cyg X-1[10], detection of hard X-rays from Her X-1 for the first time[11] were some of the early pay-offs of this programme, which is still continuing with sophisticated large area detectors like high pressure xenon counter telescopes and assembly of phoswich detectors. In 1974-75, during the lunar occultation of the Crab Nebula, two hard X-ray telescopes were flown from Hyderabad as a collabortive effort of the TIFR and the Institute for Aeronautics and Space Science, Tokyo and the University of Nagoya, and the structure of the hard X-ray emitting region of the Crab Nebula was determined[12].

The KGF Proton Decay Experiment

Right from the time of "the zero count" experiment at the largest depth of 8400 m.w.e. in the Kolar Gold Mines in 1960, which led to the programme of detection of cosmic ray induced neutrino interactions, it had been recognized that the deep underground levels at KGF would be the ideal location for an experiment to measure the life time of proton, an experiment which requires an environment free from the effects of cosmic ray secondaries. The recent developments in particle physics lending increasing credibility to gauge theoretical approaches and Grand Unification Theories focused attention on the urgent need for life time measurement. A major collaborative effort between TIFR and the Osaka City and Tokyo University groups was mounted in early 1980 and by November 1980, a 150 ton Nucleon Decay Detector with 1600 crossed proportional counters was made operational at a depth of 2300 m in a location adjacent to the site of the first series of neutrino experiments in the mines. In four years of operation, four fully confined events which are strong candidates for proton decay have been registered. In the second phase of the experiment which has started, a detector with three times higher effective tonnage for proton decay has been set up at a depth of 7000 ft below ground in a new laboratory that has been specially constructed for the experiment. The experiment is also designed for monopole search.

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B V Thosar

(A) Longitudinal Polarization of Beta-electrons

Lee and Yang had predicted the non-conservation of parity in beta-decay and that the beta-electrons emitted by radioactive nuclei should exhibit longitudinal polarization proportional to ν/C in the case of 'allowed' decays, ν being the velocity of electron; and C, that of light. This was soon confirmed in a classic experiment by C S Wu and coworkers.

In our laboratory, an electron velocity selector, using electrostatic field between two concentric metal hemispheres, had been constructed for measurements in beta-spectroscopy. This instrument was used to measure the degree of longitudinal polarization of beta electrons emitted by several radioactive nuclei, employing the process of Mott-scattering from a thin gold foil. The results showed that the $-\nu/C$ law was obeyed in the case of ^{86}Rb, ^{144}Pr, ^{60}Co, ^{147}Pm, but not for ^{115m}Cd. In this case, a deviation of about 15% from the ν/C rule was observed experimentally.

(B) Research in Nuclear Spectroscopy

Using the Siegbahn-Slatis intermediate image spectrometer and also scintillation and solid-state detectors, a number of studies on the radioactive decay of many nuclei were carried out. In this context, a thorough study of decay schemes for many nuclei was done, such as, 191 keV transition in ^{197}Au, nuclear levels of ^{199}Au, decay of ^{156}Eu and rotational band in level structure of ^{117}In. A programme of determination of internal conversion coefficients of gamma-rays in nuclei was undertaken. The most important contribution in this area was 'k-shell conversion coefficients for pure E2 transitions in some deformed nuclei', namely, $2^+ \rightarrow 0^+$ transitions in even nuclei: ^{166}Er, ^{170}Yb, ^{176}Hf, ^{186}W and ^{160}Dy. M E Rose had calculated theoretically the expected conversion coefficients for all types of nuclear transitions, including the pure electric quadrupole transitions in the nuclei mentioned above. It was reported for many years by other workers that the measured experimental values of α_k for these nuclei were about 20% higher than the expected theoretical values, for which no explanation was given. In our experiments, β-γ, x-γ and γ-γ coincidence measurements were made. All possible uncertainties in these measurements were minimized and properly evaluated. Our results showed that the experimental values of conversion coefficients agree with the theoretical values to within 6%. In support of our above findings, X-ray yields from k-shell ionization by alpha-particles for both spherical and deformed nuclei were carried out, using 5 MeV Van de Graaff machine. X-ray yields were measured in

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Sm, Tc, Ce, ^{144}Sm, ^{152}Sm, ^{154}Sm, ^{160}Gd, ^{186}W, Pb. No excess of X-ray yield was observed in the atoms of deformed even-even nuclei, when the observed data were corrected for the X-ray contribution due to internal conversion by using the theoretical values of k-shell internal conversion coefficients. The observed variation in the number of k-shell vacancies per micro-Coulomb with the atomic number indicates that the E2 internal conversion coefficients and also the probability of k-shell ionization are unaffected by nuclear deformation.

(C) Positron Annihilation Studies

Positron annihilation studies have, during the last two decades, become an effective tool in the investigation of condensed matter. My group during these years concentrated on the life-time measurements of triplet state positronium in molecular materials, solids as well as liquids. An empirical 'free volume' model was developed to explain the correlation between intensity and the longlived component in the decay of *ortho*-positronium. In the case of some saturated hydrocarbons, in the liquid phase, these measurements of life-time were taken at different temperatures. It was seen that these values of life-times could be correlated with the viscosity of a given liquid at different temperatures and with density. Such a correlation was observed for unassociated and polar liquids also, but not in the case of associated liquids, in which the presence of hydrogen bonds apparently influences the annihilation process. Positron life-times during solid-liquid phase transition in some organic systems were interpreted in terms of the 'free volume' model.

The *ortho*-positronium life-times were measured in teflon and polyethylene irradiated by gamma-rays and in polystyrene irradiated by thermal neutrons. Some measurements were also carried out in a cholesteric liquid crystal. It was possible to give interesting interpretation of some of the results on the basis of the 'free volume' model.

My group can claim credit for initiating research on positron annihilation in India and for promoting this work which is now carried out in many research centres in the country.

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B M Udgaonkar

In the early sixties, high energy cross-sections of hadrons appeared to be tamely approaching constant values, already at the energies then available, and their asymptotic behaviour appeared to be consistent with a theorem of Pomeranchuk. There was, however, no framework for describing the trends of these cross-sections at high energies. Udgaonkar was the first to point out that the proposal of Chew and Frautschi that the elastic scattering amplitude for any process is dominated by the Regge poles in the crossed channels provided the necessary theoretical framework, and that with more accurate experimental data on the cross-sections at high energies on the one hand, and with better theoretical understanding of the trajectories and residues of Regge poles corresponding to the mesonic resonances in the low energy region on the other, it should be possible to understand how the different cross-sections are approaching the Pomeranchuk limit.

This pioneering contribution of Udgaonkar[1] not only contributed substantially to the theoretical interest which was then arising in singularities in the complex angular momentum plane, but also motivated a large number of very accurate measurements of high energy cross-sections at BNL and CERN, and a considerable amount of phenomenological work in the sixties and seventies. This work corroborated Udgaonkar's expectation that 'eventhough there may be no structure in the cross-sections, there is considerable information hidden in the gentle slopes with which the total cross-sections are approaching the Pomeranchuk limit'.

In a paper with Murray Gell-Mann[2], Udgaonkar drew attention to the possibility that the high energy cross-sections of nuclei (or composite particles) could increase with energy.

Udgaonkar was invited to lecture on the developments in Regge pole phenomenology at the Scottish Universities Summer School in Theoretical Physics in 1963, and at a Summer Institute at Tokyo in 1966[3].

While simple Regge pole phenomonology has been overtaken by events, and the situation now seems to be much more complex, and there is still no satisfactory understanding of high energy cross-sections at a basic level, some of the language and tools introduced by Regge pole phenomenology still persist.

During this period, Udgaonkar (with Virendra Singh) made some important contributions to the bootstrap approach to hadron dynamics—first the bootstrap of pions and nucleons, and then the reciprocal bootstrap possibilities in SU(3)

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and SU(6), and the bootstraps in the context of the Lie Group of the strong coupling theory. These were the subjects of lectures he was invited to give at the Seminar on High Energy Physics and Elementary Particles at Trieste in 1965, and at the Summer Institute at Tokyo in 1966[4,5].

Udgaonkar was a member of the Commission on Particles and Fields of the International Union of Pure and Applied Physics, during 1969-72 and 1972-75.

During the early stages of the Indian atomic energy programme (1953-60), Udgaonkar was responsible for building the core of the Reactor Theory Group of today's BARC. He also built up a powerful broad-based theoretical physics group at TIFR, which is the leading theoretical physics group in India, enjoying a high international reputation.

During the last 15-20 years, Udgaonkar has devoted a substantial fraction of his energy to thinking, action and writing on problems of national education, and the public policy in the fields of education, science, technology and development. He has lectured and written extensively in these areas [6–19]. In these writings, he has probed into problems of importance for national development policy, to get an understanding of the education, science and technology scene, and of the weaknesses in the formulation and implementation of the national policy, strategy and planning for and through science and technology, and to project a certain perspective as to what needs to be done. These endeavours led to his becoming a member of the University Grants Commission (1973-79), to his being invited by the Deputy Chairman of the Planning Commission to the honorary position of a Special Adviser on Science and Technology (1977-79), and to his becoming a member of the Indian Council of Social Science Research (1980-83; 1983).

An unpublished note prepared by him in 1976 (incorporated in Ref. 9) for the University of Bombay became the basis for guidelines on restructuring at + 3 level that were later adopted by UGC. As a member of the UGC, Udgaonkar was instrumental in getting 'extension' accepted by the UGC as an important dimension of the functions of the university system, along with education and research; in initiating UGC action on research support to individuals and departments; in initiating a large scale faculty improvement programme; in promoting the concept of autonomous colleges, etc. He also played a substantial role in drafting the Policy Frame for the Development of Higher Education in India (1978).

Udgaonkar was instrumental in setting up the Homi Bhabha Centre for Science Education at TIFR, and the Western Regional Instrumentation Centre at the University of Bombay.

Udgaonkar has been active in Pugwash, and through his seminal paper at the Pugwash Conference at Muhlhausen in 1976[10], he became the prime mover of the Pugwash Guidelines on International Scientific Cooperation for Development, in the drafting of which also he played a key role. These guidelines in turn had a considerable influence on the G-77 preparations for the UN Conference on Science and Technology for Development at Vienna in 1979.

Udgaonkar played a critical role in the foundation of the Indian Physics

Association, was its first President, and has been editing its bulletin, *Physics News*, since 1975. His regular editorials in *Physics News* have covered a wide range of policy issues in education and science and technology, and have sometimes been reproduced elsewhere[14,16]. Udgaonkar also played an important role in starting *Pramana* as a joint publication of the Indian Academy of Sciences, the Indian National Science Academy and the Indian Physics Association, and was its Joint Editor for the first 8 years.

Udgaonkar has been active in popularization of science through Marathi, and has been the President of the Marathi Vidnyan Parishad since 1982. He participated in the preparation of a Statement on Scientific Temper, issued by the Nehru Centre, Bombay in 1981.

Udgaonkar was elected Fellow of the Indian Academy of Sciences in 1969, Fellow of Indian National Science Academy in 1984, and was President of Maharashtra Academy of Sciences during 1979-82. He is Honorary Executive Director of Homi Bhabha Fellowships Council.

Udgaonkar was awarded Padma Bhushan in 1985.

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R K Varma

It has been known, particularly since Poincare, that except for very simple exactly solvable cases, the problems of classical mechanics are, in general, nonlinear, and in most cases nonintegrable. The problem of integration in classical mechanics has occupied the attention of the greatest of mathematicians of the time, like Poincare, and Birkhoff, and in more recent times, like Poincare, and Birkhoff, and in more recent times, Kolmogoroff, Arnold, Moser, Sinai and others, who proved some very powerful general theorems. But it is only in recent times, with the aid of superfast computers, that some fascinating aspects in the behaviour of the classical mechanical systems have begun to come to light.

A classical mechanical system of *n*-degrees of freedom is defined to be completely integrable if there exist as many integrals of motion in involution (two integrals of motion are said to be in involution, if their Poisson bracket vanishes), as there are degrees of freedom. The term also applies to continuum systems which have infinite number of degrees of freedom. A continuum system is thus known to be completely integrable if it has infinitely many integrals of motion, and vice versa.

A system with less number of integrals of motion in involution than the number of degrees of freedom is "nonintegrable". Often the integrability of a system is dependent on a parameter of the system. The system may possess not an exact constant of motion, but an approximate one for the values of a parameter, say $\epsilon \ll 1$. Such approximate constants of motion are known as "adiabatic invariants". A system may thus be integrable, for values of the parameter $\epsilon \ll 1$. For $\epsilon \gtrsim 1$, the system is no longer integrable.

A completely integrable system may be transformed into a set of action-angle variables through a set of canonical transformations. These then define an *n*-dimensional *invariant torus* on which the representative point of the system lies. The addition of a small nonintegrable perturbation to the completely integrable system renders the system, strictly speaking, nonintegrable. However, the KAM (Kolmogoroff-Arnold-Moser) theorem guarantees that if the nonintegrable perturbation is sufficiently small, the invariant tori get only slightly distorted, but continue to exist. An appropriate Poincare section of the phase space will then give closed curves as cuts of the invariant tori. A sufficiently large magnitude of the nonintegrable perturbation will, on the other hand, lead first to the 'breaking up' of the invariant tori into a chain of islands (elliptic regions) and hyperbolic regions and later their

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disappearance into the sea of ergodicity as the magnitude of the perturbation is increased further.

It has been found that the transition to stochasticity in terms of the parameter characterizing the strength of the perturbation is rather sharp. A closer study of the transition region, however, reveals a highly fascinating microstructure consisting of a chain of islands laced with hyperbolic regions over successively smaller and smaller scales.

A Schrödinger-like Ensemble Description of the Behaviour of a System in the Transition Region

In certain problems of physical interest, it is necessary to find out the long time behaviour of a system in the transition region. A particularly interesting example is that of the motion of a charged particle in an inhomogeneous magnetic field. The action, μ, associated with the gyromotion of the particle (motion perpendicular to the field) is an adiabatic invariant, provided $\epsilon \equiv \frac{v_\perp}{\Omega}\frac{1}{B}\frac{\partial B}{\partial x} \ll 1$, where ϵ measures the fractional change of magnetic over a gyroradius and $\Omega = eB/mc$ is the gyrofrequency. Thus, for sufficiently small values of ϵ, μ defines an invariant torus. Making use of the invariance of μ, the complete three-dimensional motion of the charged particle can be reduced to a potential motion along the magnetic field lines, given by the equation of motion.

$$m\frac{dv_{\parallel}}{dt} = -\nabla_{\parallel}(\mu\Omega) \qquad \ldots(1)$$

Thus, trapping of a particle in the one-dimensional potential well will occur if the total energy, E, of the particle is less than the maximum height $(\mu\Omega)_{\max}$ of the potential. Since Eq. (1) is a consequence of the adiabatic invariance of μ, the trapping of the particle will hold as long as μ is a good adiabatic invariant, and, therefore, as long as ϵ is sufficiently small, Thus, predictably, when ϵ is not so small, μ will not continue to be a good invariant, and Eq. (1) will begin to be violated. This will result in the loss of particles after a certain long but finite time interval from the time of injection. The loss of particles from the so-called *adiabatic* trap is a manifestation of the violation of the *adiabatic* invariance, and the beginning of the "break-up" of the invariant torus for μ.

From the physical point of view, it is a very important problem to calculate the life time for the ensemble of particles injected into the trap. The problem is the more difficult to solve analytically or numerically, the smaller is the value of ϵ, and the greater is the residence time. The system thus belongs to the "transition region". Varma has given a somewhat novel description[1,2] of the ensemble of systems in the transition region, which is very much analogous to the quantum mechanical description. The ensemble of systems is described by a set of probability amplitudes $\Psi(n)$ governed by the following Schrödinger-like equations

$$\frac{i\mu}{n}\frac{\partial\Psi(n)}{\partial t} = -\left(\frac{\mu}{n}\right)^2\frac{1}{2m}\frac{\partial\Psi(n)}{\partial X^2} + (\mu\Omega)\,\Psi(n) \qquad \ldots(2)$$

with the total probability density $G(x,t)$ being given by:

$$G(X, t) = \sum_n \Psi^*(n)\,\Psi(n)$$

Note that these sets of equations, being analogous to the Schrödinger equation of quantum mechanics, describe the so-called nonadiabatic loss of particles from the potential well, $\mu\Omega$, due to the violation of the adiabatic invariance as being analogous to quantum tunnelling. Strange as it may seem, most of the surprising predictions of these equations have, in fact, been verified experimentally$^{3-5}$.

Quantum Mechanics as the Ensemble Description in the Transition layer

The discovery of a Schrodinger-like description of the system in the transition layer in the above example prompts one to inquire whether quantum mechanics itself can be regarded as an ensemble description of the non-adiabatic behaviour of a certain deterministic system in the transition layer. The deterministic system would then have to belong to a space at least one dimension higher than the dimensionality of the corresponding classical system; the action for the motion associated with the additional dimension should be an adiabatic invariant. When the adiabatic invariant is a good invariant, a reduced motion results on elimination of the associated coordinate. The reduced motion should be the corresponding classical mechanical motion.

When there are departures from the adiabatic invariance of the action, as there will in general be, the projections of the complete higher dimensional trajectories on the physical configuration space will depart from the corresponding classical trajectories. These departures thus belong to the transition layer and are identified with quantum effects.

In a series of articles$^{6-9}$, Varma has attempted to develop this point of view. In the context of quantum mechanics, these attempts belong to a class of theories referred to as the "hidden variable" theories for quantum mechanics. Varma has in fact been able to derive a generalization of the Schrödinger formalism of quantum mechanics as an ensemble description of the nonadiabatic effects in the transition layer. This is represented by the following set of equations similar to Eqs (1) and (2).

$$\frac{i\hbar}{n}\frac{\partial\Psi(n)}{\partial t} = -\left(\frac{\hbar}{n}\right)\frac{1}{2m}\nabla^2\Psi(n) + V\Psi(n) \quad \ldots (3)$$

$$G(\mathbf{X}, t) = \sum_n \Psi^*(n)\,\Psi(n) \quad \ldots (4)$$

where the $\Psi(n)$ are probability amplitudes which, representing, for $n \neq 1$, some new modes of quantum behaviour, are termed as the "ensemble modes". $G(x,t)$ represents the total probability density.

It may be interesting to point out that the introduction of dynamics in a higher dimensional space whose projection onto the lower dimensional space yields classical motion when the additional coordinates are cyclic, is an idea which belongs to the Hertz picture of mechanics. These ideas were developed by Varma in detail in reference 8. It is fascinating that the Hertz picture of mechanics, which can be regarded as a hidden variable theory for classical mechanics should, in fact, form a basis for a hidden variable theory for quantum mechanics. While in one paper Varma[6] sets out the basic premises of such a line of development and obtains a generalized set of Schrödinger equations, in another paper[9] he gives a more direct and instructive derivation of the same set of equations. The latter also affords an interesting comparison with the Feynman path integral formulation of quantum mechanics.

In one paper[8], Varma has tried to examine how we can understand the discrete nature of the quantum states in terms of the properties of the trajectories in the higher dimensional space. Though he has obtained some interesting results and insights, more work needs to be done to develop this point of view further.

Solitons, Stochasticity and Turbulence

Any discussion of nonlinear dynamical systems would be incomplete without a reference to the dynamics of continuum systems. In continuum systems also, as in those with finite number of degrees of freedom, there exist transitions from a coherent to chaotic behaviour as a certain parameter characterizing the system is varied. The chaotic state of the continuum system is referred to as "turbulence", while the coherent state is characterized by the existence of coherent nonlinear structures known as "solitons". Varma along with his collaborators has carried out a study of some types of solitons[10–13]. Lack of space does not permit a proper discussion of the nature of coherent and turbulent states. An elementary introduction to these topics is given in Varma's contribution[14] in the book "*Contemporary Plasma Physics*".

Epilogue

The studies of the nonlinear dynamical systems (NDS) have in recent years revealed as extremely fascinating behaviour. These studies are very important for the understanding of such basic questions as the origin of irreversibility and the foundations of statistical thermodynamics, as well as such important, if difficult, questions as the transition to the turbulent behaviour in fluids and plasmas.

We have discovered yet another fascinating aspect of at least a class of NDS. We have tried to show that even quantum behaviour of systems at the microlevel may be a property of the NDS. We wish to continue studies along these lines to advance this point of view further.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

G Venkataraman

As at present, engineering was the preferred profession when I was a student. So much so, after I obtained my B Sc (Hons) degree in physics, parental pressure compelled me to join the Electrical Engineering course at the Indian Institute of Science, Bangalore. However, seduced by the experience of assisting the TIFR Balloon Flight group during its experiments in the early fifties, I was keenly attracted to a research career in physics. Ultimately I was able to have my way and formally entered TIFR in 1955. The atomic energy programme was then under the umbrella of TIFR, and I was asked to join Dr Ramanna at Trombay.

Physics in those days had not acquired the wide differentiation which it now has. Not only was the distinction between experimentalists and theorists rather blurred, but also we did not have subjects like solid state physics. I was assigned to look into two areas: (1) The study of neutron cross-sections for the various nuclei in the keV region, and (2) the use of neutrons for studying solids and liquids. It soon became clear that I had to choose between these two subjects. Indeed many people across the world were faced with a similar choice, and depending on their preference they later came to be called either nuclear physicists or solid state physicists. I myself opted for the second choice.

I heard the word solid state physics for the first time in the mid-fifties. The transistor was making a big revolution and encouraged a deeper enquiry into the physics of solids for which the foundations had already been laid in the thirites. To aid the focus on solids, Kittel wrote his now well-known book "*Introduction to Solid State Physics*", creating a new wave.

My own work at the Atomic Energy Establishment, Trombay (later renamed Bhabha Atomic Research Centre) involved study of elementary excitations in solids and liquids using neutrons[1,2]. The papers we wrote received a fair amount of international attention, leading to the recognition of a distinctive Trombay group alongside the already well-known Harwell group, Saclay group and so on. What was perhaps more significant was that the spectrometers needed for our research were all built locally. This gave us training and a certain perspective, besides developing in all of us a Swadeshi attitude, which has been a very important part of our overall make up.

I worked for 18 years at BARC, and towards the end of my stay I became deeply involved with the study of lattice dynamics. Lattice dynamics is a very popular subject in India. My own interest in the subject was to no small extent influenced by the philosophy of Max Born.

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Born was not interested in the vibrations of crystals as such, but he found that crystals provided a good proving ground for many fundamental ideas of physics. My studies culminated in a book[3] best described as: very good reviews but very poor sales!

In late 1973, I was transferred to the Reactor Research Centre* (RRC), Kalpakkam, to organize various physics-based and related programmes. This was a totally new experience for me. I resisted the temptation of continuing my previous interests and starting programmes in lattice dynamics, etc. In retrospect, I believe this was a wise decision. I looked around and discovered that RRC was primarily a technology-oriented organization with a strong focus on fast breeder technology. Nuclear engineers there were mostly concerned about the damage produced in structural materials by fast neutron bombardment. This process, known as radiation damage, produces defects but our training as solid state physicists had hardly taught us anything about defects. In fact, defects feature only in the last chapter of most books on solid state physics and very few people get to the last chapter! I resolved that RRC should have a programme with a strong focus not only on defects but also on the physical basis of mechanical behaviour in general. My previous training in physics helped me to introduce perspectives unusual in metallurgical physics. In particular, I was able to enthuse many people into exploring the role of fluctuations in determining the mechanical properties of solids[4,5]. In the process I discovered that unlike areas like semiconductor technology and so on, the technology of structural materials had not benefited much from physics, largely because of the snapping of contacts between metallurgists and physicists in the thirties. I strove hard to bring about a dialogue between physicists and metallurgists in the country, one example of which was a discussion meeting I arranged under the sponsorship of the Indian Academy of Sciences[6]. The meeting itself was a success, but it served to bring home to me the painful truth that physicists and metallurgists are not yet ready for working together!

During the years I have been at Kalpakkam, solid state physics itself has undergone a transformation, bifurcating into materials science and condensed matter physics. A materials scientist is deeply involved with properties of specific materials or a class of materials. A condensed matter physicist, on the other hand, is interested in phenomena rather than specific materials.

In condensed matter physics itself one is now witnessing a remarkable revolution in the unification of many states like glass, liquid crystals, crystals, quasi-crystals, etc., all under one umbrella, that of symmetry and symmetry breaking. This has also provided deep insight into the defect state of matter and how defects are coded into the basic symmetry of the system.

Deeply engrossed in this pursuit, I sought and was fortunate to be awarded a Jawaharlal Nehru Fellowship to study the relationship between symmetry and imperfections, specifically with reference to condensed matter. The Fellowship has been a very fruitful experience for me personally, and I have also been able to motivate many young scientists to get into this area.

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*Now renamed Indira Gandhi Centre for research.

When the Fellowship ends and I make my re-entry into the Department of Atomic Energy, I suppose I will have to involve myself with more organizational work, especialy in relation to applied physics. However, I do not have any regrets, for I strongly believe that there is an urgent need to improve our instrumentation capabilities. Even though my publication list may suffer, I would be more than happy if I could enthuse at least some of my fellow physicists into becoming as strong as their counterparts abroad in instrumentation. It is not enough to do science or engineering in isolated pockets. A horizontal traffic of concepts and ideas is very much necessary but is sadly missing in the Indian scene. If I could somehow do something to promote this in the years to come, my career would have been worthwhile.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Putcha Venkateswarlu

After completing his BSc at the Andhra Christian College, Guntur, and his MSc at Banaras Hindu University, Putcha Venkateswarlu started research work as a student of Prof. R K Asundi at Banaras in 1944. Groups of diffuse bands and continuous bands were obtained in I_2, Br_2, Cl_2, ICl and IBr and explained on the basis of transition from stable upper levels to a number of repulsive states[1,2]. After completing his DSc at Banaras in 1947, Venkateswarlu proceeded to the Institute of Theoretical Physics, Copenhagen, Denmark, where he worked with Prof. Niels Bohr and his associates in nuclear physics as a Rask Osted Foundation Scholar during the period 1947-48 on problems connected with the stopping[3] and straggling of protons[4] in metal foils using a Van de Graaff accelerator. From there, he went to the University of Chicago to work with Prof. R S Mulliken as post-doctoral fellow in molecular spectroscopy during the period 1948-49. He worked there on the spectroscopy of I_2, CCl and CF_2 molecules. CF_2 was the first triatomic free radical to be found and correctly identified[5].

Venkateswarlu worked with Dr G Herzberg as a post-doctoral fellow at the National Research Council of Canada in Ottawa during the period 1949-50 and studied for the first time the infrared spectroscopy of CH_3CN and CH_3CCl_3. After this, he worked on the infrared spectroscopy of allene and propylene as a research associate with Prof. R C Lord in the spectroscopy laboratory, Massachusetts Institute of Technology. The results on the vibration rotation studies on CH_3CN[6] and allene[7] proved to be interesting and important. Of all the molecules belonging to different point groups which do not have dipole moment in their ground states, only those belonging to point groups D_2d and T_d do not have centre of symmetry. Mizushima and Venkateswarlu[8] showed in 1953 from group theoretical considerations that molecules like CH_4 which belong to the point group T_d possess nonvanishing dipole moment in the triply degenerate excited states F_2, while the molecules like allene which belong to the point group D_{2d} have dipole moments in the doubly degenerate excited states E. After the advent of laser spectroscopy using resonance techniques, Luntz and Brewer [*J chem Phys*, **54** (1971) 3641; *Science*, **178** (1972) 217] and Curl and Oka [*J chem Phys*, **58** (1973) 4908] confirmed the above prediction and measured the dipole moment of CH_4 and the microwave transition in the excited F_2 state. While working with Prof. Walter Gordy and his associates, first as a research associate during the period 1952-54 and then as a visiting scientist during the period 1959-60, Venkateswarlu studied the microwave millimetre wave spectroscopy of

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CH_3OH[9,10], $GeCl_3$ and CH_3CN. The work on the first two molecules gave their molecular structure, while that on the third gave precise and useful information about the ℓ type doubling[11] in the molecule.

Venkateswarlu was a faculty member for the period 1954-61 in the Aligarh Muslim University. He and his Ph.D. students, R D Verma, B N Khanna, T S Jaseja, K V L N Sastry, B D N Rao, D R Rao, Y V Rao, P R K Sarma and A Sundararajan, have developed laboratories for microwave spectroscopy, nuclear magnetic resonance (NMR) optical spectroscopy, including vacuum ultraviolet spectroscopy, and electron paramagnetic resonance and obtained interesting results in these areas. Venkateswarlu and Verma[12,13] obtained new band systems in Br_2 and IBr, while Venkateswarlu and Khanna[14] obtained a new band system in Cl_2. Some of these systems are now found by others to be good lasing systems. The new band systems obtained by Sarma and Venkateswarlu[15,16] in SnBr and SnCl appear to be also promising for laser action. Resonance series have been found by Rao and Venkateswarlu[17,18] in Br_2 and Cl_2 in the vacuum ultraviolet region which are good candidates for lasers in that region. Good work on microwave spectroscopy of CH_3OH and CH_3NH_2 leading to information regarding hindered rotation has been done by Sastry at Aligarh. Considerable high resolution NMR work has been done in substituted benzenes having four spin systems by Rao and Venkateswarlu[19] and in substituted fluorobenzenes by Aruldhas and Venkateswarlu[20].

Venkateswarlu was a faculty member in the Indian Institute of Technology, Kanpur for the period 1961-82, where he, his students and his associates, D R Rao, T S Jaseja, G Chakrapani and G C Upreti, developed laboratories for optical spectroscopy, EPR, lasers and laser spectroscopy. About 33 of his students completed their PhD in these laboratories.

A considerable effort was put on the studies in EPR of transition metal ions and rare earth ions doped in single crystals in which 12 students completed their PhD. In addition to spin Hamiltonian parameters, these studies gave information regarding site symmetry, lattice defects and phase transitions in different crystals[21-35] studied.

Chowdari and Venkateswarlu[21] studied the EPR of the $(NH_4)_2SO_4$: Mn^{2+} system and showed that Mn^{2+} substitutes α-NH_4^+ and gets associated with β-NH_4^+ vacancy or vice versa. The *z*-axis of the complex is found to make an angle of 18° from the *b*-axis in the *bc* plane. It is found that probably because of the loss of the mirror symmetry, the complexes which are Magnetically equivalent in the paraelectric phase become inequivalent in the ferroelectric phase (below 223K) and the EPR lines get doubled.

Sastry and Venkateswarlu[22] studied the EPR of VO^{2+} doped in NH_4Cl. At room temperature, an isotropic spectrum indicating a fast readjustment of VO^{2+} in the crystal has been obtained, while at low temperature an anisotropic spectrum is obtained. The disorder-order phase transition temperature in this crystal corresponds to the temperature where the isotropic spectrum changes over to anisotropic spectrum. Rao, Sastry and Venkateswarlu[23,24] studied the change of isotropic to anisotropic spectra in $NaNO_3$, KNO_3, $CsNO_3$, NH_4NO_3 and $Ba(NO_3)_2$ and found that the spectroscopic transition temperatures in the last two crystals correspond to the respective phase transition temperatures in these crystals, while there is no correspondence between the spectroscopic transition temperatures in $NaNO_3$, KNO_3 and $CsNO_3$ crystals and their respective phase transition temperatures[20,21]. Shrivastava and Venkateswarlu[25] found a good correlation between the EPR spectral changes and the phase transitions in KNO_3 doped with Mn^{2+}.

Dayal, Rao and Venkateswarlu[26] studied the EPR of Mn^{2+} in $Cd(ClO_4)_2.6H_2O$ from 328K to liquid nitrogen temperature. The site symmetry of Cd^{2+} is trigonal with a water octahedron distorted parallel to the crystallographic *c*-axis. Mn^{2+} substitutes for Cd^{2+} and exhibits a characteristic 30 line hyperfine spectrum at room temperature (298K) for the magnetic field H along the *e*-axis. On lowering the temperature, two phase transitions are found to occur, one at 272 ± 1K and the other at 115.5 ± 1K, which were not reported earlier.

Dayal, Rao and Venkateswarlu[27] have also studied the EPR of Mn^{2+} in $Mg(C1O_4)_2.6H_2O$. Room temperature studies show three inequivalent sites for Mn^{2+} in the crystal. Hyperfine forbidden transitions are observed when the magnetic field is not oriented along one of the principal axes. Two structural phase transitions have been observed, one at 272 ± 1K and the other at 103 ± 1K. The transition occurring at 272 ± 1K has been observed for the first time, while the other at 103 ± 1K is the one detected earlier through Mössbauer studies.

The EPR of Mn^{2+} in $(NH_4)_2SeO_4$ single crystal has been studied by Jain and Venkateswarlu[28] between 77 and 395K. The principal *y*-axis of the magnetic complex is along the *b*-axis and the principal *z*-axis makes an angle 54° ± 2° with c-axis in the *ac* plane. Around 390K, the spectrum shows an anomalous change in line shapes followed by a complete collapse of the spectrum, which is found to be reversible. This has been discussed in terms of a possible first order phase transition. The spectra at 77K and at 300 K, involving the transitions $\triangle M = \pm 1$ and $\Delta m = \pm 2$ have been observed. From the unequal separations between $\Delta m = \pm 1$ doublets in the $M = +1/2 - 1/2$ transition, the values of the axial and rhombic parts of the quadrupole coupling constants are determined.

EPR of Mn^{2+} doped iron, cobalt and nickel perchlorate hexahydrates (FePH, CoPH and NiPH) has been studied by Dayal, Rao and Venkateswarlu[29] from room temperature to liquid nitrogen temperature. The temperature variation study shows phase transitions at 237 ± 5, 154.5 ± 6.5 and 223 ± 5K in FePH, CoPH and NiPH respectively.

Venkateswarlu, along with Singh and Upreti[30,31], studied the EPR of Gd^{3+} in single crystals of various paramagnetic rare earth salts and obtained their zero field splittings. Super-hyperfine structure[32] of Mn^{2+}: NaF was investigated by Jaganadham and Venkateswarlu and that of Cu^{2+} : NH_4Br by Sastry and Venkateswarlu[33], giving precise information about the site symmetry and lattice defects. Venkateswarlu, along with Pandey[34], studied the EPR of $(NH_4)_2SO_4$: VO^{2+} system to obtain the components of the g-tensor and the spin Hamiltonian parameters giving the precise position of the VO^{2+} ion in the crystal.

While studying EPR of the transition metal ions in single crystals, optical spectroscopy of some of these systems has been carried out. From such studies, Mehra and Venkateswarlu[36,37] obtained the crystal field parameters or the spin orbit coupling parameter of Mn^{2+} in $RbMnF_3$. Narayana, Mehra and Venkateswarlu[38] studied the optical absorption spectra of cobalt and nickel acetate hydrate crystals, while Mehra and Venkateswarlu[39] studied manganese acetate crystals; in all these crystals the corresponding crystal field parameters have been obtained. Narayana and Venkateswarlu[40] observed changes in the absorption spectra of $NH_4C1 : Co^{2+}$ at phase transition temperature, indicating the usefulness of the technique in studying phase transitions. Around the same time, Venkateswarlu and Verma studied the vibrational spectra and rotational isomerism of polyatomic molecules[41].

Venkateswarlu started laser spectroscopy work during 1968-70 in the laboratory of Prof. H P Broida, Department of Physics, University of California, Santa Barbara, where he was a visiting professor/NSF senior scientist fellow. Raman spectra of NH_4C1, KDP, Cs_2SO_4[42] and $(NH_4)_2SO_4$[43] single crystals were studied. The polarization behaviour of the Raman lines in different crystal orientations was studied to understand the phonons of different symmetries. Symmetry coordinate of Raman active lattice modes was worked out in Cs_2SO_4 from group theoretical concepts[42]. Work on excited fluorescence of rare earth ions in LaF_3 crystals was started there by Venkateswarlu and was continued later in Kanpur after the development of laser laboratories over there.

Venkateswarlu was a senior visiting scientist at the National Research Council of Canada, Ottawa, during the periods 1967-1968 and 1976-1977. He was a visiting professor in the Department of Chemistry, University of British Columbia, Vancouver, B.C., Canada, during 1972-73. During these periods and later in Kanpur, he worked on various problems related to the vacuum ultraviolet spectra of I_2, Br_2, $C1_2$ and ICI and high resolution spectra of I_2, Br_2 and N_2. Rydberg series[44–46] in I_2, Br_2 and IC1 have been obtained which enabled the determination of inoization potentials of these molecules. A number of new high lying valence states have also been detected in these molecules. Venkateswarlu, Sarma and Rao[47] reported 12 resonance doublet series in the vacuum ultraviolet region in Br_2 excited by different atomic lines of Br_2 atom. Analysis of these series enabled determination of the ground state vibrational and rotational constants of the Br_2 molecule from $\upsilon'' = 0$ to 76.

Venkateswarlu, Murty and Basu[48] studied the second positive band system of N_2 under high resolution just below and just at laser threshold. Rotational structure and Λ doubling in 15 bands have been reported. The high resolution spectrum of the N_2 laser was studied and it was found that some of the rotational transitions can be made to lase selectively by collision with helium atoms.

Venkateswarlu, Pramila and Rao[49] carried out high resolution studies on I_2 in the presence of argon and Venkateswarlu, Khanjilal and Rao studied Br_2 in a similar manner. These studies helped to determine the vibrational and rotational constants in these molecules precisely.

Laboratories for lasers and laser spectroscopy were developed in Indian Institute of Technology, Kanpur by Venkateswarlu, T S Jaseja, D R Rao and G Chakrapani with the help of a number of graduate students and research associates. He-Ne lasers, CO_2 lasers, pulsed and CW Ar^+ lasers have been fabricated. Commercial He-Ne lasers, N_2 laser, excimer laser, ruby lasers, Nd^{3+} : YAG laser and different laser systems have also been obtained at the Indian Institute of Technology, Kanpur, with grants from various funding agencies. Kumar, Rao and Venkateswarlu[50] observed two photon processes and self-absorption in the laser excited fluorescence in $LaF_3 : Nd^{3+}$ crystal. Reddy and Venkateswarlu[51] observed energy upconversion processes and two-photon (STEP) process to be responsible for the population drain mechanism from the lower D levels to the upper L levels. They observed energy transfer processes[52] between Nd^{3+} and Pr^{3+} to be responsible for selectively exciting Pr^{3+} to $^1D_2$ levels. They recently[53] found in $LaF_3 : Nd^{3+}$ that R_1 level gets more quenched than R_2, that S levels fluoresce because of thermalization from the lower R levels and that ions in D and Y levels undergo energy transfer interaction, causing upconverted fluorescence from E levels.

As a visiting professor in the Louisiana State University in 1982, Venkateswarlu, along with Kumar and McGlynn, began to study the laser photoacoustic spectra[54] of I_2, Br_2 and IC1. He joined the Physics Faculty in the Alabama A and M Universtiy, Huntsville, Alabama in September 1982, where a new Graduate Program in Optics and Material Science was started a year earlier. Venkateswarlu and M C George, in association with H Jagannath, G Chakrapani and Y V Rao, developed laboratories for optics and laser spectroscopy. The following research projects have been undertaken:

(1) *Volume holography and optical phase conjugation in photorefractive crystals $BaTuO_3$ and BANANA*—Dynamic holograms are formed in these crystals using two coherent beams for He-Ne or CW Ar^+ lasers. Parametric studies on these gratings and the optical phase conjugation are going on[55]. It is found that the decay of the grating and phase conjugation in $BaTiO_3$ involves a sum of two exponentials, indicating that two processes are involved in the growth and decay of holographic grating and optical phase conjugation in $BaTiO_3$ and three processes are involved in BANANA. Work is going on to find out the origin of these processes.

(2) *Laser photoacoustic spectroscopy of halogens and mixed halogens*—The molecules are excited to upper states using N_2 laser pumped dye laser and excimer pumped dye laser. Due to nonradiative relaxation, I_2 and IC1 have shown photoacoustic spectra in the visible region. The first two involve transitions from the ground state to the $B^3\pi(2)$ state, while the third involves a transition to the $^3\pi(1)$ state.

The photoacoustic spectrum of IC1 indicates nonradiative relaxation from the $^3\pi(lu)$ state to the groud χ $'\Sigma^+(0^+)$ and the $A'^3\pi(2)$ states. Experiments are in progress to understand these relaxations. The project involves investigations to find out the vertical positions of the upper repulsive states that dissociate into $^2p_{1/2} + {}^2p_{1/2}$ atoms or $^2p_{3/2} + {}^2p_{1/2}$ atoms. If these vertical positions are known, solar radiation with monochromatic filters can be used to dissociate the molecule into $^2p_{1/2}$ states which when going down to $^2p_{3/2}$ states release energy for useful purposes.

(3) *Optical studies in laser dyes*—The absorption and fluorescence of laser dyes are systematically recorded to obtain their energy level structure. Excited state absorption (transient absorption) from the first singlet state to higher singlet states in rhodamine 6G, POPOP, dimethyl POPOP and α-NPO are recorded and analysed[56]. One of the problems of interest is to find out the effect of the excited singlet absorption on the efficiency of the dye laser operation.

(4) *Multiphoton transitions and Rydberg states in molecules*—Dye lasers pumped by N_2 laser, excimer laser and a ring dye laser pumped by Ar^+ laser are used to reach Rydberg states in molecules. Fluorescence transitions from the excited levels to different vibrational rotational levels of the lower state give precise information about the molecular constants and electronic nature of the upper and lower states. Infrared and microwave radiations also are used in these multiple resonance processes. Rydberg-Rydberg transitions, Rydberg-Rydberg state perturbations, quantum defects, etc. will be studied under this project.

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Ajit Ram Verma

One of the outstanding unsolved problems in 1950 was in the field of crystal growth. It was known that a crystal can grow layer by layer and form an ideally perfect crystal. But a mathematical examination of the problem by a group led by Prof F C Frank showed that on this mechanism it will take an infinitely long time for a crystal to grow to finite sizes at low supersaturations. During experimention, crystals do grow at finite rates at low supersaturations. There was enormous discrepancy between theory and experiment.

At this stage, Frank put forward his screw dislocation theory of crystal growth, which could explain the growth. A crystal which has grown by screw dislocation mechanism was expected to exhibit growth spiral features on its surface with molecular step heights. If was thought at that time that by the available techniques, it will not be possible to observe the molecular growth spirals, much less measure these molecular step heights. It was with this background that Verma started his work on crystal growth at the Royal Holloway College, London in 1950. His contributions are discussed below in brief.

(1) Verma was among the first 2-3 persons who gave in 1950-51 experimental evidence in support of the dislocation theory of crystal growth by taking microphotographs of molecular growth spirals on silicon carbide crystal faces (0001) using phase contrast microscopy. He utilized the multiple-beam interferometric techniques to measure these step heights which were only 15 Å (on 6H SiC crystal). His measurements showed these step heights to be equal to the X-ray unit cell size, or to be simply related to them. This measurement uniquely established these spiral features to be molecular growth spirals originating from screw dislocation[1,2].

While other workers using optical technique utilized the bright field illumination, Verma used phase contrast microscopy for photographing these spiral features and demonstrated phase contrast microscopy to be a very superior technique for molecular observations. Though phase contrast microscopy had been invented much earlier, it was only in 1950-51 when Verma photographed these spirals and measured their molecular step heights, that the great power of this technique was realized. The following quotation from the Nobel citation of Prof. Zernicke in 1953 brings out this point:

"…..In this connection, Zernicke's phase-plate serves as an indicator which locates and measures small surface irregularities to a fraction of light wavelength. This sharpness of depth is so great that it penetrates to the point at

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which the atomic structure of the substance begins to become manifest....."

(2) Silicon carbide, a material chosen by Verma for these studies, was known to be polytypic in structure, with unit cell dimensions differing from polytype to polytype along the C-axis. The unit cells of some of these polytypes are several hundred angstroms in height. To exhibit order over such large distances, which is far beyond the range of any atomic forces, posed a problem.

Verma isolated specimens of different silicon carbide polytypes with spiral features and measured their spiral heights and X-ray unit cells. He showed that the step heights are equal to the unit cell dimensions parallel to the step direction in different polytypes. This observation immediately suggests a relationship between the formation of the X-ray unit cell size and the growth spiral step height as a result of dislocation. On this basis, Frank gave the theory of formation of polytypes as a result of growth from screw dislocation. This would then explain the large periodicities much beyond the range of atomic forces.

An account of this work formed Verma's PhD thesis and was published in the form of a book "*Crystal Growth and Dislocations* (Butterworth, London, 1953). This was the first book on this topic and was translated into Russian by the USSR Academy of Sciences in 1959.

(3) Then followed a great spurt in the theoretical and experimental work to understand the interesting problem of polytypism in different crystals. Verma and his group at Banaras Hindu University studied this problem in detail by optical and X-ray diffraction techniques. Jointly with Prof. P Krishna, another book "*Polymorphism and Polytypism in Crystals*" (John Wiley, 1966) was brought out to present systematically the problem and the state of knowledge. This book was also translated into Russian by the USSR Academy of Sciences in 1966.

The phenomenon of polytypism has now assumed even greater importance and Vol. 7 of *Progress in Crystal Growth and Characterization* has been devoted to "Crystal Growth and Characterization of Polytype Structures" (Pergamon Press, 1984). This book has been dedicated to Verma for his pioneering studies in this field.

The work of Verma has been cited at numerous places, but special mention may be made to the following two:

(a) *Science in History* by J D Bernal (Watts, London, 1954, 1957) gives a whole plate facing page 585 reproducing two photographs of a single and double spiral on silicon carbide crystals.

(b) *Introduction to Solid State Physics* by C. Kittel (1971) reproduces on page 691 phase contrast micrographs of growth spirals on silicon carbide crystals.

(4) During his directorship at the National Physical Laboratory, New Delhi (1965-1982), Verma enlarged his activities, which included research and development work in applied technology, experimental work for the realization of fundamental units of physical measurement by quantum phenomena, preparation of materials, their characterization from the device point of view, etc. In fundamental research, Verma pursued his scientific interest in the area of crystal growth and lattice imperfections and their characterization and established a strong group under Dr Krishan Lal on

experimental studies in this area, with special emphasis on the development of sophisticated equipment. The techniques and equipment successfully developed[3] include (i) special crystal pullers, (ii) diffractometers for high resolution X-ray diffraction characterization of nearly perfect crystals, and (iii) topographic systems for the study of lattice imperfections. These systems give a precision at the highest international standards. These facilities have enabled the preparation of crystals with controlled perfection and purity. Several problems related to dynamical scattering of X-rays, diffuse X-ray scattering from nearly perfect crystals to study the contribution from phonons and imperfections[4], electric field-induced defects in semiconducting and insulating single crystals are currently being studied. It is also proposed to study diamonds, especially Sir C V Raman's collection, with these new techniques.

The International Union of Crystallography sponsored the International School on Synthesis, Crystal Growth and Characterization of Materials for Energy Conversion and Storage, at the National Physical Laboratory, New Delhi, during October 1981, in honour of Verma's 60th birthday. The proceedings of this school have been published as a book, "*Synthesis, Crystal Growth and Characterization*" (edited by Krishan Lal, North Holland & Co., Holland, 1982). It begins with the article by Verma "Crystal growth and lattice imperfections—Interferometric and X-ray diffraction studies: Reminiscences", which gives a brief connected account of the several active schools of research established by Verma and his students on the study of solid state, with special reference to crystal growth and lattice imperfections. Mention may be made of the following:

(a) Delhi University with Prof. G C Trigunayat.

(b) Banaras Hindu University with Prof. P Krishna, Prof. O N Srivastava and Govind Singh.

(c) Roorkee University with Prof. Vinod K Srivastava.

(d) National Physical Laboratory with Dr Krishan Lal.

(6) As Jawaharlal Nehru Fellow (1982-1984), Verma has written a book on "*National Measurement and Standards System for India*" which will be published soon.

Selected Publications

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R Vijayaraghavan

Vijayaraghavan is currently head of the Solid State Physics and Materials Science group at Tata Institute of Fundamental Research. Joining the institute in 1951, as a research student, over the years, he has built a group using local talents, facilities and equipment which is now comparable to some of the best groups in the developed nations. The research facilities consist of building and maintaining sophisticated NMR and Mössbauer spectrometers, allied furnaces, susceptibility and other bulk property measuring equipment. At present, the group consists of several senior scientists who are respected internationally.

Right from the beginning, the microscopic properties of a system were correlated with macroscopic properties and a useful understanding regarding electronic properties of solids was acquired. For example, the bulk susceptibility in transition metal alloys was correlated with the spin density at the nuclear sites. This gave interesting results on d band magnetism. Similarly, the conduction electron polarization in rare earth alloys was shown to be oscillatory. The effect of crystal fields on susceptibility, spin density and magnetism of samarium alloys was demonstrated using bulk and nuclear techniques. Many of these results were obtained for the first time. Recently, the group has made pioneering contributions in the case of valence fluctuations and spin glasses. The dynamical and static properties of spin glasses were demonstrated in both alloys and insulators by a judicious combination of several techniques. New valence fluctuating systems with interesting magnetic and superconducting properties were synthesized for the first time. Amorphous alloys, quasi-crystals and microparticles are currently being investigated.

Vijayaraghavan was the recipient of Shanti Swarup Bhatnagar award for Physical Sciences in 1976. He was elected member of the Magnetism Commission of IUPAP for three terms (1975-78; 1978-81 and 1984-87).

Selected Publications

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2. Vijayaraghavan R, Magnetic behaviour of RRh_3B_2 ternary borides, *Curr Sci*, **52** (11) (1983) 518-27.
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4. Malik S K, Dhar S K & Vijayaraghavan R, Structural and magnetic investigations of some new boron containing rare earth intermetallic compounds, *Bull Mater Sci*, **6** (2) (1984) 263-72.

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5. Srinivasan R, Usha S, Sampathkumaran E V & Vijayaraghavan R, High pressure magnetic susceptibility of the intermediate valence system EuPd$_2$Si$_2$, *J Phys F Met Phys*, **14** (1984) L33-L35.
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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Virendra Singh

Most of my work has been in the area of strong interaction dynamics. The basic approach used was analyticity and symmetry. My more recent work deals with unusual phenomena encountered in field theory wherein either soliton background fields or boundary conditions play an important role as well as with string theories. I discuss briefly some of my contributions below in approximately chronological order.

(1) Regge Poles

I investigated the analyticity of Coulomb scattering amplitude in the complex angular momentum plane[1]. As an example which can be exactly solved, it was very illuminating. It was reproduced in the book "*Complex Angular Momenta and Particle Physics*", edited by E J Squires (W A Benjamin, New York, 1963) and by Physical Society of Japan in their series of *Selected Papers in Physics* (147), edited by R Kubo.

The analysis of high energy pion-nucleon scattering using Regge pole theory[2] constituted essentially my thesis with Prof G F Chew. The importance of the helicity amplitudes, in the Regge pole context, was emphasized here first. This became the standard way to analyse this process at high energies.

I was also involved in a project to investigate (with M Gell-Mann, M L Goldberger, F E Low and F Zachariasen) whether elementary particles in the conventional field theory could convert themselves into Regge poles, i.e. Reggeise, as a result of higher order processes[3]. In contrast to the case of spinor electrodynamics, the scalar particles in the scalar electrodynamics do not Reggeise.

(2) Symmetry

Assuming that the decay interaction transforms as an octet operator of unitary symmetry SU(3), the decay of baryon decuplet into the baryon and meson octets was investigated and a number of sum rules obtained[1]. One of these sum rules connecting various decays into pion, known as Gupta-Singh sum rule, gives a good account of these processes. It was a common practice for a long time to compare the status of this sum rule with the latest data in particle data tables.

The SU(6) symmetry was quite successful in giving the correct spectrum of hadron states. The masses of the hadrons, in this symmetry scheme, received their explanation in the work leading to Bég-Singh SU(6) mass formula[5]. The level spacings in the baryon resonance decimet were related to those in the lowest baryon octet.

(3) Bootstrap Theory

Among the large number of

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investigations on bootstrap theory to understand the particle spectrum, I would like to cite my series of three papers on Lie Group of Strong Coupling Theory[6]. Here, strong interaction coupling constant ratios were obtained in a rather elegant manner. Equivalence of Lie group theory to static bootstrap was established. An unusual instance of dynamical symmetry generation was pointed out.

(4) Current Algebra Amplitudes

The discovery of a fixed pole at $J = 1$ in the current algebra amplitudes was made while analysing Fubini sum rule[7]. The discovery was simultaneously made by B W Lee, F Law *et al* also.

The classical low energy theorems, such as those giving Thomson scattering, and those due to F Low and Gell-Mann-Goldberger, give terms up to first order in energy for the Compton scattering amplitude. These are exact to all orders in strong interactions and to lowest order in eletromagnetism. A deeper analysis revealed that for certain parts of the amplitude, such theorems can be extended, thus giving terms of higher order in energy as well[8,9]. These were totally unexpected results. An extention of these results to spin-one targets was done by A Pais and as such some of these theorems are known as Singh-Pais theorems. A crucial role was played in this development by a lemma proved earlier in this connection and known as Singh's lemma[8]. These low energy theorems were later generalized to fourth order in *e* as well.

(5) High Energy Theorems

A number of useful and exact restrictions on the high energy behaviour of strong interactions follow from the general principles of quantum field theory, such as unitarity, crossing, analyticity and polynomial boundedness. The earlier work on these theorems was due to M Froissart, A Martin and others. Our investigations led to a resurgence of interest in the subject and we obtained a large number of exact results (for a review *see* Ref 10). Especially important were our results on particle-antiparticle total cross-section differences[11] and those giving upper bounds on the elastic scattering amplitudes[12] (Singh-Roy bounds).

Rigorous sum rules and bounds were also obtained on pion-pion scattering length[13].

An offshoot of this work was our exact solution of a number of Meiman problems arising from work on form factors (for a review *see* Ref. 14)

(6) Foundations of Quantum Mechanics

Bell's inequality provides a test of local hidden variable theories versus quantum mechanics. We showed as to how these can be generalized[15]. We also looked into their completeness.

(7) Potential Theory

We applied the analytic theory of continued fractions to anharmonic oscillators[16], a class of confinement potentials, rotating harmonic oscillator, etc., to obtain an exact theorem on the coupling constant analyticity domains (with S N Biswas *et al*).

Our generalization of higher order JWKB expressions for energy levels and wavefunctions at origin were useful for upsilon resortances (with J Pasupaty).

We found all possible solitons in Schrödinger equation which propagate without change of shape. We proposed new generalized coherent states for the Schrödinger equation (with S M Roy).

(8) Proton Decay

An effective baryon-lepton coupling model for the phenomenological analysis of baryon number violating decays of a baryon was proposed (with K V L Sarma)[17]. It was also reported at the Solvay conference.

(9) Quantum Field Theory with Solitons and/or Boundary Conditions

Here I would especially mention two investigations (with S M Roy):

(i) Exact solution of Schrödinger equation in Aharonov-Bohm plus Dirac-Monopole Potential[18], and

(ii) Fractional fermion number induced by solitons and boundary conditions[19].

(iii) Bosonic Strings with new boundary conditions[20].

Selected Publications

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4. Gupta V & Virendra Singh, Sum rules for the decay of the baryon decuplet into the baryon and meson octets in broken SU(3) symmetry, *Phys Rev*, **135** (1964) B1442-44.
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10. Virendra Singh, Exact results in the analytic S-matrix theory of strong interactions for high energies, fields and quanta, **1** (1971) 151-70.
11. Roy S M & Virendra Singh, Upper bounds on particle-antiparticle total cross-section differences at high energies, *Phys Lett*, **32B** (1970) 50-54.
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13. Roy S M & Virendra Singh, Rigorous sum rules and bounds on pion-pion scattering lengths, *Phys Lett*, **60B** (1975) 67-70.
14. Virendra Singh & Raina A K, Bounds on form factors and propagators, *Forts Phys*, **27** (1979) 561-79.
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19. Roy S M & Virendra Singh, Fractional total charge eigenvalue for a fermion in a finite one dimensional box, *Phys Lett*, **143B** (1984) 179-82.
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Sectional Committee—III : Chemical Sciences

(Analytical, Inorganic, Physical and Theoretical Chemistry)

U C Agarwala

Inorganic Complexes Having Short-Lived Di- or Tri-Atomic Molecules as Coligands

The excitment one gets from the study of unstable di- or tri-atomic molecules like COS, NS, SO, NSe, etc. stems from the diversity in the chemistry of closely related molecules, e.g. (NS, NO, NSe), (CO, COS, CS_2), which is unpredictable from *à priori* theory. There is no other choice except to explore it experimentally. Our conviction or at least some hope of gaining some understanding of the reaction chemistry of these molecules through the study of related molecules (e.g., NS, NO) on comparable transition metal systems has incited us to explore this area.

Attempts have been made to study the following aspects of COS chemistry:

(a) Its activation by various transition metal ions, especially in low oxidation state.

(b) Its insertion reactions into M-H, M-O and M-N bonds to get monothioformates, monothiocarbonates and monothiocarbamates, respectively.

(c) Its reactions in the coordinated state.

(d) Its photolytic reactions with potential application in carbonylation reactions.

In order to achieve this goal, a large number of reactions (both thermal and photolytic) with ruthenium, rhodium and iridium complexes in various oxidation states have been carried out and the results published[1-3]. It has been shown that COS can be a good starting point for carbonylation reactions.

A large number of metal nitrosyls have been synthesized and studied theoretically, but even the initiation of the metal thionitrosyls had not been introduced because of lack of suitable thionitrosylating agents, prior to our work. The syntheses of a large number of metal thionitrosyls have been developed. An interesting and surprising part of this work is the variety which NS displays in its mode of bonding with the metal ions. It could be possible to bind NS or NSC1 with the metal ions as NS^+, NS^-, NS bridging, NSC1 molecule, $(NSC1)^{2-}$ (ref. 4-6). Our initial studies suggest a direct relationship between the mode of bonding and the metal ion. Further, in some metal thionitrosyls, the bonded NS could pick up an atom of atmospheric oxygen to yield either bonded $—NSO^-$ or monothionitrite $\left(—N\lessgtr\genfrac{}{}{0pt}{}{S}{O}\right)^-$. Will it not be exciting to search for answers to the questions: Under what conditions which type of bonding will NS have with an element? Does the type of bonding have

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any relationship with the oxidation state of the metal ion? And finally, the questions of 'how' and 'why' will have to be solved. Attempts will also be directed towards inserting NS molecule into M-A bond, where A can be any non-metallic element.

Another molecule which has interested us considerably is SO. Its life time is very short. In order to hook this molecule to the metal ion, it is necessary to trap it in *situ* during any reaction. Stilbene sulphoxide is such a molecule which gave SO in a solvent and has been trapped by rhodium to give SO complex[7]. The development of its chemistry is our futuristic aim.

We also propose to develop the coordination chemistry of more unstable molecules like S_2O, C_3O, PS, PO, etc. having very short life; the study will be extended to more unstable interesting intermediates generated during a reaction which are unknown. This concept has been utilized for developing new nitrosylating agents like N-nitroso derivatives; it has been observed that the substituents attached to the nitrogen atom play an important part in the liberation of the NO group[8]. Besides the development of these nitrosylating agents, NOX ($X = Cl^-$, Br^-, Br_3^-, NO_3^-, NO_2^-) has been shown to be a very good nitrosylating agent[9-12]). During this work, it was possible to develop conditions under which NO could be reduced to NH_3 in one step[13], a process having potential for use in nitrogen fixation.

Mixed Valence Complexes

Mixed valence complexes even today are a challenge for both experimental and theoretical chemists. The crucial issue is the assessment of the degree of electronic coupling between two ligand bridged subunits. In the course of our investigation of linkage isomers of monothiocyanato-pentaammineruthenium (III) complex[14], a new synthetic route was developed[15] for an unusual linking of pentaammineruthenium (II) and pentaammineruthenium (III) moieties through thiocyanato bridge. In terms of the Robin-Day classification, this mixed valence complex is characterized as delocalized or class III. This is unusual, because here the two units are linked through a heteroatom system.

Abstraction of CO from Alcohols

A process for the abstraction of carbon monoxide from aliphatic primary and secondary alcohols using ruthenium (III) complexes has been developed[16] and utilized in the syntheses of carbonyls. The work will be extended to di, tri and polyketones.

Other Work

(1) Normal coordinate analyses of inorganic complexes required for the assignment of various IR bands[17].

(2) Study of the nature of M-S bond in the inorganic complexes having metal ions bonded to sulphur ligands.

(3) Study of the nature of bonds formed between metal and various donor atoms utilizing the X-ray spectroscopic techniques[18].

(4) Study of the percentage covalency in the bonds formed between europium (III) and various donor atoms using Mössbauer effect with europium source. This work resulted in the finding that the bond Eu-D is not mostly ionic as was believed previously but has a large covalent character[19].

(3) A large number of substitution reactions of the sterically hindered molecule $Ru(\eta^5\text{-}C_5H_5)XA_2$ have been carried out[20-22]. An interesting feature of these complexes is that when $Ru(\eta^5\text{-}C_5H_5)SnCl_3P_2$ was allowed to react with NOX ($X = Cl^-, Br^-, Br_3^-, NO_2^-$), CP was substituted by phosphine in which one of the phenyl group was π-bonded with ruthenium.

Besides a review on the chemistry of thionitrosyl[23], Agarwala has published a few books[8,24,25].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

J C Ahluwalia

Ahluwalia has made significant contribution in areas of current research interest in physical chemistry. These areas include thermochemistry, structure and physical chemistry of aqueous and mixed aqueous-non-aqueous solutions, and hydrophobic hydration of biopolymer model systems.

His work has been published in leading international journals and has been cited widely. His review[1] which appeared in *Chemical Society Reviews* was widely acclaimed as an important contribution and stimulated further research in this frontier area. Ahluwalia has participated in several national and international conferences and symposia.

The main objective of his research work is to understand the nature of interaction of solutes, particularly hydrophobic solutes, with water and water-non-aqueous mixed solvent systems, which is now recognized as an important factor in understanding the conformation of biopolymers and proteins in aqueous solutions. He was among the first few scientists who initiated the application of calorimetrically determined heat capacity changes as a powerful tool for determining the structural changes which occur when a solute is dissolved in water. By measuring precise and accurate thermodynamic quantities, such as integral enthalpies of solution, partial molar heat capacities and partial molar volumes at infinite dilution (where only solute-solvent interactions are involved) and at various temperatures with the help of calorimeters fabricated in his laboratory, Ahluwalia and his associates were able to study the hydrophobic hydration of model solute systems[2–18], such as quaternary ammonium halide salts[2,11,12–17], sodium carboxylates and surfactants[8–10], amino acids and peptides[2,4,5,9], sugars[3,6,7], etc. His findings have resulted in important contributions as to the effect of size, nature of solute and temperature variation on the hydrophobic hydration of hydrophobic solutes. He has also quantitatively measured the effect of CH_2 group increment in the alkyl chain length of non-polar moiety of the solute on the heat capacity and hydrophobic hydration or structure enhancing propensity of the above-mentioned hydrophobic solutes.

Through systematic studies on heat capacities of amino acids which are the main constituents of proteins and polypeptides, Ahluwalia has found that the heat capacity contribution of CH_2 group in α-amino acid remains constant and is same as that in monofunctional compounds, indicating that the hydrophobic character of an alkyl chain increases linearly with the number of carbon atoms in the chain length when the functional group (or groups) is attached at

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one end of side chain. Study of branched and normal chain acids shows that branching has no effect on the hydrophobic hydration propensity of the non-polar groups. However, in the case of amino acids other than α-amino acids, it has been found that as the separation of the charged groups NH_3^+ and COO^--increases, the mutual interaction increases, modifying the overall hydration propensity of these amino acids. This effect is observed only when the charge separation does not exceed five bond lengths. The finding[9] of Ahluwalia that the peptide unit CONH- contributes positive partial molar heat capacity emphasizes the need for taking this into account in any discussion on additivity of group heat capacity in a protein molecule. The positive heat capacity contribution of a peptide unit has been explained on the basis of temperature dependence of hydrogen bonding of the peptide groups with water.

The partial specific volume of a protein is a characteristic parameter that has been used to elucidate several processes which depend on the protein conformation or during which the protein conformation changes, e.g. protein aggregation or polymerization, conformational transitions of proteins and polypeptides, and antigen-antibody reactions. The changes in the partial specific volume of the macromolecules during such processes depend on the intra- and intermolecular interactions as well as on the electrostriction of the solvent due to the charged moieties present in the macromolecule and on the charge-neutralization processes. However, due to the structural complexities, it is extremely difficult to separate the various contributions that give rise to the observed volume changes in macromolecular reactions. Volume changes in such reactions have been explained by using volume data on small model compounds.

Ahluwalia determined the apparent molar volumes of a large number of amino acids. N-acetylamino acids and peptides in aqueous solutions from precise density measurements and examined the group additivity relationships from the V_2^0 data on α-amino acids, N-acetylaminoacids and peptides as well as from those of several homologous series of compounds[2]. It has been shown that the presence of hydrophobic groups in close proximity in α-amino acids and N-acetylamino acids decreases the functional group contributions as well as the contribution due to hydrophobic hydration of the alkyl groups from those observed in the mono-functional compounds. The V_2^0 contributions of nonpolar side chains agree with those obtained from additivity. The influence of hydrophobic and charged centres on the V_2^0 contribution of another hydrophobic group is reflected in the V_2^0 values of CONH groups and other hydrophobic side chains. In general, the values of V_2^0 of the peptide group or hydrophilic side chains are smaller compared to those obtained from additivity. Therefore, for the prediction of V_2^0 values of higher peptides, the side-chain and peptide group contributions obtained from the α-amino acids or N-acetylamino acids should be used. The concentration dependence of the apparent molar volumes of these solutes has been explained in terms of the combined effects of hydrophilic and hydrophobic solute-solute interactions mediated through the typical structure of water.

Ahluwalia's study of thermodynamics of hydrophobic hydration of model solutes, particularly those of amino acids and peptides in aqueous solution of protein denaturants, such as urea, guanidine hydrochloride and alcohol, has contributed significantly towards a better understanding of the mechanism of protein denaturation[4,5,7].

His recent thermodynamic work[3,6] on aqueous solutions of mono- and disaccharides has shown the failure of group additivity rule to predict the heat capacities of these compounds. His work indicates that there is extensive hydrogen bonding between sugar molecules and water, which depends on the stereochemistry of these compounds.

From direct calorimetrically determined enthalpies and heat capacities of micellization of some such surfactants as sodium dodecyl sulphate (NaDDS), hexadecyltrimethyl ammonium bromide (HTAB), ($HPB.H_2O$), hexadecyl pyridinium bromide ($HPB.H_2O$), Ahluwalia has shown that 25% of hydration of alkyl chains is retained in the micelles of these surfactants[18].

Currently, Ahluwalia is engaged in the thermodynamic investigation of biochemically important model compounds, such as nucleic acid bases, nucleosides, nucleotides, etc. in aqueous solutions with a view to understanding the nature of interactions of these compounds in aqueous solutions, particularly the extent of contributions from H-bonding and stacking interactions in addition to those of hydrophobic interactions.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Balbhadra Prasad

In 1929, after getting my Honours degree from the London University, I joined Ravenshaw College, Cuttack (then under Patna University) as Assistant Professor of Chemistry. My first work was on viscosity of liquids and dependence of viscosity constant on constitutional factors. It was shown that β in the viscosity (η) equation $\log \eta = \alpha + \frac{\beta}{T}$ depended on constitutional factors[1]. I also showed that β in the above equation depended on boiling point and critical temperature of the liquid concerned[2]. Later, I proved that the viscosity of fused salts also follows the same equation[3]. I also showed that in the case of associated liquids, the value of β decreases with temperature and then at higher temperature becomes constant. The value of β at lower temperature divided by its value at a higher temperature is a measure of molecular association[4].

My second line of work was based on experiments done by us in Ravenshaw College on viscosity of aqueous solutions mainly meant to test Falken Hagen-Vernon equation of viscosity of solutions: $\eta/\eta_0 = 1 + A\sqrt{C} + BC$, where η is the viscosity of solution; η_0, the viscosity of the solvent; A is derived from Debye Hückel theory of strong electrolytes; and B is an empirical constant. A number of experiments were performed at 35°C. In work done with A S Chacravarti, viscosity and density of aqueous solutions of barium chloride, magnesium chloride, cobalt chloride and nickel chloride were measured at 35°C[5]. These experiments also confirmed Falken-Hagen-Vernon equation. So did many other experiments performed by us. Viscosity and density of mercuric chloride were measured and the value of A was found to be zero, showing that mercuric chloride behaves as a non-electrolyte[6].

I also worked on electrolytes using liquid junction potential. As part of studies on the behaviour of bi-univalent salts in aqueous solutions, dissociation constants of Cd-Ac^+ and Cd Ac_2 were calculated[7] from studies on salt bridges. It was found that KBr is as good a salt bridge as KCl[8]

I became Director of Public Instruction, Orissa in 1952, Vice-Chancellor, Patna University in 1957 and Vice-Chancellor, Allahabad University in 1961. In 1965, I went back to research and continued my work up to 1980 at Patna University. Examining work done by us with liquid junction potential, I found that liquid junction potential rose up to 2 mV in some experiments. Hence, it was decided not to use liquid junction potential. We thought of using Davies equation:

$$\log f_1 = 0.5\, Z_1^2 \left(\frac{I^{1/2}}{I + I^{1/2}} + 0.2\, I \right)$$

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where *I* is ionic strength. Davies had assumed that the empirical term used by him depended entirely on the valency of the ion and was absolutely independent of its composition. On examination it was found that empirical term of ions having the same valency was not the same in all cases, but changed from ion to ion. The empirical term in the modified equation was constant for an ion unless a drastic change was made in the ion atmosphere. It was, however, additive. This modified equation was used prior to its formal publication[9] to solve a number of problems. It constituted another line of my work. No approximate dissociation constant was used. Study of ionic equilibria in aqueous solutions of chlorides of magnesium, calcium, strontium and barium gave the idea of modification of Davies equation[10]. The second and first dissociation constants of oxalic acid were determined[11,12]. The second dissociation constant of phosphoric acid, a recalculation from alkaline solutions using modified Davies equation, was also determined[13]. This recalculation showed the effect of drastic change due to change in ionic atmosphere.

The determination of the third dissociation constant of phosphoric acid from 283.15 to 323.15 K was an extremely difficult work[14]. Only our group has done this work electrolytically and over an extensive temperature range. Many other workers have tried this by several methods at one temperature. Essentially, our work has been on hydrolysis of PO_4^{3-} ion. The cell used by us was $H_2(Pt)/Na_2HPO_4, NaOH, NaCl, AgCl/Ag$.

For determining the standard potential of mercury-mercurous electrode at a number of temperatures (5-35°C) an interesting method was used[15].

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V Baliah

Baliah has done research in the field of organic chemistry and physical organic chemistry. His chief contributions may be listed as follows: (1) developed an elegant method for the synthesis of piperidin-4-ones; (2) made an extensive study of the isomerization of aryl arenesulphonates to hydroxydiaryl sulphones; (3) synthesized a large number of β-amino and α, β-unsaturated sulphones; (4) synthesized many interesting 1,4-thiazines, tetrahydrothiopyrans and bicyclic compounds; (5) established the conformations of some substituted cyclohexanes, piperidines, tetrahydrothiopyrans and bicyclic compounds; (6) elucidated several polar and steric effects by the application of physical methods; (7) studied the applicability of linear free energy relationships to naphthalene derivatives; (8) investigated d-orbital resonance involving sulphur, chlorine, bromine and iodine; and (9) discovered steric enhancement of resonance.

Synthesis and Stereochemistry of Piperidine Derivatives

An elegant method of synthesizing 2, 6-diarylpiperidin-4-ones was developed[1]. Earlier, the reaction, then known as the Petrenko-Kritschenko reaction, was limited to the condensation of an ester of acetonedicarboxylic acid with an aromatic aldehyde and ammonia or a primary amine, leading to the formation of 2,6-diaryl-4-oxopiperidine-3, 5-dicarboxylate or its N-substituted derivative. The reaction was later extended to aliphatic aldehydes and several amines by Mannich, but the products were mixtures of several compounds and their separation was not easy.

The importance of the work of Baliah *et al.* lies not only in the simplicity of the procedure but also in the use of acetone and other aliphatic ketones[2] in place of esters of acetonedicarboxylic acid. The yields are very high with practically no side reactions. A large number of piperidin-4-ones have thus been synthesized, employing various aldehydes and ammonium acetate or methylamine.

Using sulphonyldiacetic acid and its esters in place of ketones, thiomorpholine derivatives were obtained in excellent yields[3].

A number of piperidin-4-ones were reduced to the secondary alcohols. The MPV reduction, reduction by sodium and alcohol, catalytic reduction, and complex metal hydride reductions led to the formation of epimeric mixtures of secondary alcohols. The epimeric alcohols were designated as α- and β-forms. The α-form has the OH group *cis* to the 2,6-diaryl groups and is equatorially oriented in a normal chair form. The β-isomer has OH *trans* to the aryl groups, the orientation

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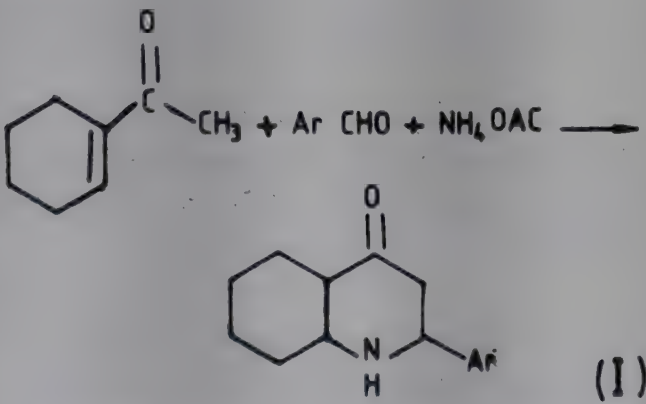
being axial. The different methods of reduction give the α- and β-forms in varying ratio, e.g. the MPV method affords only the β-isomer and LAH reduction gives the α-form predominantly.

The remarkably easy synthesis of substituted piperidines by the method of Baliah stimulated investigations on their stereochemistry in several parts of the world.

Synthesis and Stereochemistry of Substituted Decahydroquinolin-4-ones

Employing the above method of synthesis of piperidin-4-ones, substituted decahydroquinolin-4-ones have been prepared in a remarkably simple manner[4]. Thus, Δ^1-acetylcyclohexene condenses with aromatic aldehydes and ammonium acetate to yield 2-aryl-decahydroquinoline-4-ones.

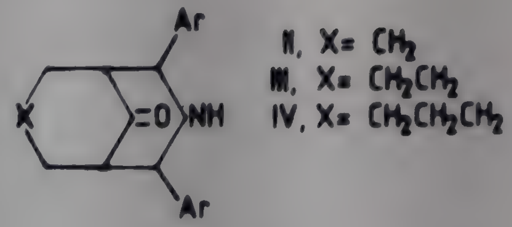


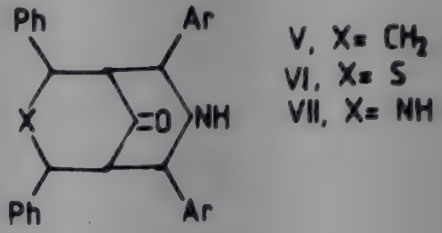
(I)

The ring fusion in I has been established to be *trans* through kinetic and spectral studies.

Synthesis and Stereochemistry of Bicyclic Compounds

A number of bicyclic compounds have been synthesized[5,6]; 2,4-diaryl-3-azabicyclo [3.3.1] nonan-9-ones (II), 7,9-diaryl-8-azabicyclo [4.3.1] decan-10-ones (III) and 8,10-diaryl-9-azabicyclo [5.3.1] undecan-11-ones (IV), 2,4-diaryl-6,8-diphenyl-3-azabicyclo [3.3.1] nonan-9-ones (V), 2, 4-diphenyl-6, 8-diaryl-3-thia-7-azabicyclo [3.3.1] nonan-4-ones (VI) and 2,4-diphenyl-6,8-diaryl-3,7-diazabicyclo [3.3.1] nonan-4-ones (VII). They have been reduced to alcohols. Each ketone yielded a pair of epimeric alcohols. The conformations of these alcohols have been studied by spectral and kinetic methods. The conformational studies have considerable importance due to the fact that these molecules can have a twin-chair, chair-boat or twin-boat conformation. The bicyclic compounds synthesized by Baliah *et al.* have aroused interest at several leading centres of stereochemical research in Europe and America and have led to conformational studies by different techniques.





Conformation Analysis of Some Substituted Cyclohexanes

The rates of quaternization of a number of substituted N,N-dimethylcyclohexylamines with methyl iodide in methanol were measured and the conformations of these compounds were established from the kinetic data[7]. The conformational energy for the dimethylamino group was calculated and found to be —2.3 kcal mol^{-1} at 30°C and that for the phenyl group -3.0 kcal mol^{-1}. The kinetic data indicated that *trans*-3,3,5-trimethyl and 4,4,5,5-tetramethyl-N,N-dimethycyclohexylamine exist in the non-chair conformation.

Fries Rearrangement of Aryl Arenesulphonates

The rearrangement of aryl arenesulphonates to hydroxydiaryl sulphones remained practically uninvestigated until Baliah and his coworkers made an extensive study of it[8,9]. The rearrangement of aryl naphthalenesulphonates was also investigated and the structures of the resulting hydroxy sulphones were established by synthesizing them unequivocally.

Nature of the S-O Bond in Sulphones and P-O Bond in Phosphine Oxides

Studies of the solvent effect on the UV spectra of sulphones and phosphine oxides threw light on the nature of the S-O and P-O bonds[10,11]. After an analysis of the diamagnetic susceptibilities of about 70 compounds, the contribution of oxygen to the magnetic susceptibilities of sulphoxides, sulphones, phosphine oxides, arsine oxides and stilbine oxides indicated that the oxygen is linked by a co-ordinate covalent bond in these compounds. The contribution of sulphur in phosphine sulphides, arsine sulphides and stilbine sulphides indicated that the sulphur atom in these compounds is also similarly bonded.

Applicability of Hammett Equation to Naphthalene Derivatives

Although extensive studies were made to correlate the reactivities of *meta*- and *para*-substituted benzene derivatives, relatively few studies were made in this direction for the derivatives of naphthalene and other polynuclear hydrocarbons; so several reactions with naphthalene derivatives were investigated kinetically and the applicability of the Hammett equation to them was examined.

d-Orbital Resonance Involving Sulphur and Halogens Other than Fluorine

Physical methods such as dipole moment measurements, absorption spectroscopy and diamagnetic susceptibility measurements were used to study d-orbital resonance[12,13]. For example, electric dipole moments of *p*-aminophenyl methyl sulphide and *p*-dimethylaminophenyl methyl sulphide have been shown to indicate that sulphur enters into d-orbital resonance in these compounds. By an analysis of the basicities of *p*-halogenoanilines, the acidities of *p*-halogenophenols, and the UV spectra of *p*-substituted halogenobenzenes, it has been shown that chlorine, bromine and iodine enter into d-orbital resonance in these compounds.

Discovery of Steric Enhancement of Resonance

Although steric inhibition of resonance was well known, steric enhancement of resonance was unknown until Baliah discovered it in 1960[14] while analysing the electric dipole moments of some substituted anisoles. Since then he and his coworkers published a number of papers, furnishing additional evidence for the phenomenon. This evidence is based on studies involving rates of reactions, equilibria of reactions, dipole moments and diamagnetic suseptibilities of benzene derivatives.

Convincing evidence for steric enhancement of resonance may be seen in the rate data given in Table 1[15].

Table 1—Solvolysis of substituted benzyl chlorides

Substituents	$10^4k(\mathrm{min}^{-1})$	*Relative rate*
H	8.3	1.0
m-Me	10.8	1.3
p-OMe	130	15.7
3-Me, 4-OMe	510	61.4
3-Me, 4-OMe, 5-Me	3.7	0.4

4-Methoxy-3-methylbenzyl chloride undergoes solvolysis at a much higher rate than 4-methoxybenzyl chloride, indicating steric enhancement of resonance, while 4-methoxy-3,5-dimethylbenzyl chloride undergoes solvolysis at a much slower rate than 4-methoxybenzyl chloride, indicating steric enhancement of resonance. The large increase in the rate of 4-methoxy-3-methylbenzyl chloride shows that the ability of the 4-methoxy group to release electrons in the former is significantly higher than that of the methoxy group in 4-methoxy-3,5-dimethylbenzyl chloride. This has been explained as follows.

The 3-methyl makes the adjacent O-Me adopt a preferred orientation *trans* to it. Consequently, the probability of the methoxy group becoming coplanar with the benzene ring increases and its resonance also increases, resulting in greater electron release.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

D K Banerjee

The investigations of Banerjee have been confined to synthetic organic chemistry, study of reaction mechanisms, spectrometry and X-ray crystallography.

The earliest synthetic effort of Banerjee provided the first synthetic confirmation[1] of the structure of aloe-emodin, a unique naturally occurring hydroxyanthraquinone, having a carbinol group and the active principle of aloes, rhuburb, etc. The stereospecific synthesis of *dl*-equilenin methyl ether[2] constitutes the first stereospecific synthesis of a natural steroid, *d*-equilenin, because of the demethylation of the metyl ether followed by resolution of the resulting *dl*-equilenin having been carried out by earlier workers. This was followed by two novel stereospecific syntheses[3,4] and lately one more[5] of the equilenin molecule.

The female sex hormone estrone and its three isomers, including lumiestrone, were synthesized[6] in association with Johnson and his group. Later, presumably the first stereospecific synthesis of estrone was realized[7]. The first conversion of an equilenane molecule to the estrane was also achieved[8].

Utilizing the method developed for the synthesis of equilenin methyl ether, two important tricyclic synthones, viz. *trans*-1-hydroxy-8-methyl-4, 5-(4′-methoxy-benzo)-hydrindane and 1-hydroxy-8-methyl-4,5-(3′-methyl-4′-methoxybenzo)-hydrindane were prepared[2]. The proper enantiomer of the first one was used by Velluz *et al.* for the development of the synthesis, for the first time, suitable for the industrial production of medicinally important steroids. The second tricyclic compound was utilized for the first synthesis of 8-isotestosterone[9,10], conformationally an extremely interesting molecule, and its anthracene analogue and also for the synthesis of *dl*-9, 11-dehydrotestosterone and *dl*-testosterone[11].

Marrian *el al.* had isolated a urinary steroid metabolite, known as Kober Chromogen KC6A, and its structure was determined as *d*-18-hydroxyestrone. Barton and coworkers had reported multi-step conversion of *d*-estrone to the metabolite. A formal synthesis of it was achieved later[12]. A lot of confusion existed around a second urinary steroid, 3β-hydroxy-17-keto-5(10) 6,8-estratriene, isolated by Heard and Hoffman, which was cleared up by its synthesis[13] from equilenin. Along with it, an unambiguous synthesis of *d*-8-iso-10-iso-19-nortestosterone from *d*-equilenin was also accomplished.

A synthesis of a bicyclic synthone, *d1*-2-formyl-6-methyl-7 β-hydroxy-4 : 3 : 0-2,9)-nonadiene, was reported[14]. Recently, a chiral synthesis of the optically active compound has been achieved[15]. It has

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been possible to convert this compound into a tricyclic dienone, which is expected to serve as a key intermediate for the development of a new stereospecific method for the synthesis of nonaromatic steroids. Work on the development of a novel simple method for the synthesis of nonaromatic steroids of medicinal importance is also in progress.

In the field of terpenes, valeranone, the first of a unique group of nonisoprenoid sesquiterpene ketones with two angular methyls, was synthesized[16]. The total synthesis of the sesquiterpene, α-selinene, was also reported[17]. The elucidation of structure and configurations of the isomeric C-11 acids has played a crucial role in the diterpene chemistry. For the first time, the absolute confirmation of these structures and configurations has been provided by their synthesis[18]. A new synthesis of a tricyclic synthone, methyl 13-hydroxydeisopropyldehydroabietate, for the terpene and steroid synthesis, has been accomplished giving improved yield and consisting of fewer steps than those employed by previous workers, using abietic acid as the starting material[19].

The contradictory observations that diethyl β-ethoxycarbonylpimelate on cyclization with sodium in benzene gave a six-membered ring and ethyl 2-ethoxycarbonylcyclopentanone-2-acetate and that the former compound on treatment with ethanolic sodium ethoxide formed a cyclopentanone ring led to a thorough study of the mechanism of the Dieckmann cyclization and the problem was solved with the help of decisive experiments. This study resulted in the preparation of several synthones by the cyclization of different polyesters, which have been utilized in the total syntheses of steroids[20].

A novel dehydrogenation-addition reaction involving abietic acid and tetrachloro-o-benzoquinone was observed. The structure of the product and the mechanism of the reaction were proved through UV, IR, NMR and mass spectral studies. The product has been utilized, as mentioned earlier, in the preparation of a tricyclic synthone likely to prove useful in the terpene and steroid syntheses[21].

The mechanism of a reaction involving the substitution of cyclopentanone-2-carboxylic ester was solved[22].

An unusual UV absorption at 247 nm (log ϵ 3.6) was observed for the saturated dicyano esters obtained by the addition of hydrogen cyanide to α,β-unsaturated cyano esters. This absorption was there in ethanol, but absent in heptane or actonitrile; further, the intensity of the band increased with the dilution of the ethanolic solution. Study of the UV absorption of a number of related compounds proved that this was due to the enolization of the dicyano esters to form the ketinimine group[23].

Study of the IR spectra of the polyhalophenols and their ethers has shown that both the aromatic and the C-O stretching bands are shifted to lower frequencies; while the shift of aromatic stretching vibrations has been shown to be due to the inductive effect of the halogen substituents, the shift of the C-O vibrations has been demonstrated to be due to the overcrowding by the halogen atoms[24].

Djerassi had obtained 8-isotestosterone by a multi-step conversion of diosgenin. Djerassi's observations that the compound exhibited androgenic activity by the capon unit test, its ORD curve was quite different from that of testosterone and the B-ring was boat shaped, made the molecule very interesting. Conformational study of the mode of total synthesis of the compound[9,10] also suggested that the B-ring should be in the boat shape. Crystallographic study of the synthetic *dl*-8-isotestosterone was carried out[25], which confirmed the structure and configuration of the molecule, showing that the B-ring was in the twist form and the difference in the ORD data of 8-isotestosterone and testosterone was due to the strong nonbonded interaction existing between the C-10 methyl and the C-11 methylene. To explain the physiological activities of testosterone and 19-nortestosterone and their isomers, *d*-8-iso-10-isotestosterone, *d*-8-iso-19-nortestosterone and *d*-19-nortestosterone were also studied by X-ray crystallography (Bhadbbade *et al.*, unpublished work) and the results lent support to Liao's view on androgenic activity. Currently, the solid derivatives of α- and β-cyperones are being examined by X-ray crystallography, as α- and β-cyperones also exhibit difference in the ORD data similar to that for testosterone and 8-isotestosterone.

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Sadhan Basu

The present investigations deal with charge transfer (CT) interactions of various polynuclear hydrocarbons in their electronically excited states. The hydrocarbons in their electronically excited states give rise to exciplexes with potential electron donors like N,N′-dialkyl anilines or even with another molecule of its own type in the ground state to give excited state dimers or excimers. The process of CT complex formation in general may be represented as

$$A \xrightarrow{h\nu} A^* \qquad \ldots(1)$$

$$A^* \rightarrow A + h\nu_o \qquad \ldots(2)$$

$$A^* + D \rightarrow (AD)^* \qquad \ldots(3)$$

$$(AD)^* \rightarrow A + D + h\nu_D \qquad \ldots(4)$$

A is the hydrocarbon under consideration acting as the acceptor in its electronically excited state (A^*); ν_o, its monomer emission frequency; ν_D, the exciplex emission frequency obtainable from the CT complex $(AD)^*$ when A^* combines with the donor *D*.

We are here interested in the nature of the charge transfer complex $(AD)^*$. This molecule may be made up of both exciton and charge-resonance contributions as

$A^*D \rightleftharpoons AD^*$	$(A^-D^+) \rightleftharpoons (A^+D^-)^*$
Exciton contribution	Charge-resonance contribution.

In μ_e is the dipole moment of the CT complex (in the excited state), the extent of stabilization of the complex in a solvent with dielectric constant 'ϵ' and refractive index '*n*' may be shown to be

$$\Delta W' = \frac{2\mu_e^2}{a^3}\,\frac{\epsilon - 1}{\epsilon + 2} - \frac{n^2 - 1}{n^2 + 2}$$

a is the Onsager cavity radius.

Obviously, in different solvents, the extent of stabilization will vary and hence the plot of $\frac{\Delta W'}{h} = \nu_0 - \nu_D$ vs

$$\frac{\epsilon - 1}{\epsilon + 2} - \frac{n^2 - 1}{n^2 + 2}$$

will be linear; the slope of the plot will give the dipole moment 'μ_e' of the CT complex. Assuming that a 100% charge resonance contribution will correspond to a dipole moment 'μ_e' = 15 D, the extent of 'charge resonance' state in the exciplex may be obtained. The relevant experimental data are given in Table 1.

It is thus observed that the charge resonance contribution to the exciplex extends from 70 to 80%. It was observed earlier that charge resonance contribution to pyrene-pyrene excimer is roughly 20%.

The geometry of the CT complex may be investigated from the observations of

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Table 1 Dipole Moments and CT Contributions of Different CT Complexes

Acceptor	Donor	Dipole moment of CT complex	Percentage of charge resonance contribution
Pyrene	DMA	12.1	81
Pyrene	DEA	12.1	81
Anthracene	DMA	11.8	77
Anthracene	DEA	11.8	77
Benzpyrene	DMA	11.3	75.3
Phenanthrene	DMA	12.2	81.33
Chrysene	DMA	12.5	83.3

depolarization factors $\left(\rho = \frac{I = - I_{\perp}}{I = + I_{\perp}} \right)$ of their emission spectra at different wavelengths. If the CT complex possesses a sandwich configuration, then the state of polarization of the excimer/exciplex will be at right angles to the state of polarization of the monomer emission, the latter being polarized in the plane of the molecule. Hence, the CT-complex with D_{2h} symmetry species will obey the theoretical values as predicted by Perrin-Joblonsky and will pass from positive to negative while passing from monomer to CT complex emission band. Moreover, it will possess the extreme values of + 1/3 at the monomer emission and − 1/7 at the CT complex emission wavelengths, since their respective fluorescence intensities at the corresponding maxima are rather pure. With $10^{-2}M$ pyrene in benzene in solid glass media (22% polystyrene system), the same was observed.

Deviations from the theoretical values of ρ would therefore mean deviation from D_{2h} symmetry and the values of 'ρ' at the excimer/exciplex maxima enable us to calculate the angle (β) between the monomer and bimer oscillators as per the relationship $\rho = \frac{3 \cos^2 \beta - 1}{7 - 3 \cos^2 \beta}$

This reveals a lot of ideas about the molecular geometry of the CT complexes. The data obtained with different CT-complexes and monomer fluorescence spectra of different systems are given in Tables 2 and 3.

Table 2—Depolarization Values and Oscillator Angles of Different Hydrocarbons in 22% Polystyrene Medium

System	Solvent	Oscillator angle (β) deg
Pyrene	Cyclohexane	54.7
	Benzene	67.1
	Chloroform	62
	n-Butyl-acetate	65.4
Anthracene	Cyclohexane	63.5
	Benzene	67.1
	Chloroform	61.1
	n-Butyl acetate	58.2
Benzpyrene	Cyclohexane	59.0
	Benzene	58.2
	Chloroform	59.5
	n-Butyl acetate	59.8
Methylcolanthrene	Cyclohexane	66.2
	Benzene	58.2
	Chloroform	61.5
	n-Butyl acetate	64.6

Table 3—Depolarization Values and Oscillator Angles of Pyrene-DMA and Anthracene-DMA systems in 22% Polystyrene in Different Solvents

System	Solvent	Oscillator angle (β) deg
Pyrene-DMA	Cyclohexane	47.7
	Benzene	36.8
	Chloroform	53.7
	n-Butyl acetate	47.7
Anthracene-DMA	Cyclohexane	45.8
	Benzene	47.7
	Chloroform	52.7
	n-Butyl acetate	47.7

It may also be observed that where the vibration bands of the monomer emission overlap with the excimer emission band, the change of sign of the depolarization factor 'ρ' may serve as a means to verify the possibility of location of excimer formation in excited state of the molecule. This was observed with anthracene and methylcolanthin.

In the case of CT interaction in the ground state or even in the excited state, the associated energy may be expressed as:

$$\nu_{CT} = I_D - E_A - \Delta$$

where ν_{CT} is the CT-frequency; I_D, the ionization potential of the donor, E_A, the electron affinity of the acceptor, and Δ, the stabilization energy of the ion-pair.

With the same donor 'D', however, ν_{CT} would vary linearly with E_A, the electron affinity of different hydrocarbons serving as acceptors. As with the hydrocarbons, the excited states involved are the π^* states, the corresponding E_A values may be estimated from homo (highest occupied molecular orbitals) and obtainable from the data supplied by Coulson and Streitwieser [*Dictionary of π-electron calculations*, Vol. 2 (Pergamon Press, London), 1975].

It is observed that ν_{CT} for a number of systems as plotted against $\dfrac{\alpha - \alpha_0}{\beta}$ obeys good linear correlation. The observations in benzene solvent are given in Table 4.

Table 4 — ν_{CT} vs $(\alpha - \alpha_0)\beta$

Hydrocarbon	Donor	ν_{CT}	$h\nu_{CT}$ ev	$(\alpha - \alpha_0)/\beta$
Perylene		20,000	2.48	0.347
3:4-Benzpyrene		21,276	2.63	0.371
Anthracene	DMA	21,740	2.69	0.414
Pyrene		22,730	2.81	0.445
Chrysene		23,530	2.91	0.520

This certainly establishes that the aniline always serves as the donor.

Most of the information obtained about excited state charge-transfer interaction is indirect. To get a better insight into the whole process, it is necessary to make life time measurements or even better still record time resolved emission spectra which will give a clearer insight into the process by which one system passes on to the other and at what rate.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

D S Bhakuni

Nitrogen heterocyclic molecules are found extensively in biological systems and have been chosen by nature to be involved in many, if not most, of the fundamental reactions of living organisms. Nucleosides and nucleotides are vital components of all living cells and are intimately involved in protein synthesis, storage and transfer of genetic information. Some of these molecules are also constituents of certain co-enzymes involved in a variety of oxidation-reduction and electron transfer processes.

Bhakuni has made significant contributions on different aspects of nucleosides[1–3]. He has modulated the biological activity of these compounds by chemical transformation. Such studies, apart from offering the possibilities of finding new drugs, have also contributed much to our understanding of the structure-activity relationship. Significant changes in biological activities have been observed by making changes in sugar and/or purine or pyrimidine moieties in nucleosides. Analogues of natural nucleosides either emulate or antagonize the functions of the naturally occurring purines and thus exhibit a wide variety of specific biological activities. Such activities are largely due to the structural similarities of these nucleosides to the natural enzyme substrates. His future interests are conformational studies on biologically active molecules, their interaction at receptor site, mode of action at cellular level and metabolic fate in the living system.

Bhakuni has made outstanding contributions on different aspects of alkaloids, the nitrogen heterocyclic molecules that occur in plants[4]. He has isolated several biologically active alkaloids with novel structures from Indian medicinal plants and established their structures and stereochemistries[5–7]. He has also studied their conformations and achieved the synthesis of some of the bases on biogenetic pattern.

The art by which nature makes biologically active molecules is very fascinating. Bhakuni has traced biogenetic pathways for benzylisoquinolines[8], proaporphines, aporphines[9], tetrahydroprotoberberines[10], normal and abnormal *Erythrina*[11], *Tylophora*[12], bisbenzylisoquinoline[13], biphenylbisbenzylisoquinoline[14], 1-benzylaporphine[15], dibenz (d,f) azonine[16] and morphinandienone[17] alkaloids and aristolochic acid[18]. With the help of radio-labelled substrates of known configuration, he has studied the specificity of enzymic reactions. He has introduced a new and novel biosynthetic approach for determining the absolute configuration of biphenylbisbenzylisoquinoline alkaloids[19]. He has also studied

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aberrations in the biosynthesis of aporphine and tetrahydroprotoberberine alkaloids.

Enzymatic studies in biosynthesis, isolation of biologically active molecules from marine animals and plants are his future interests.

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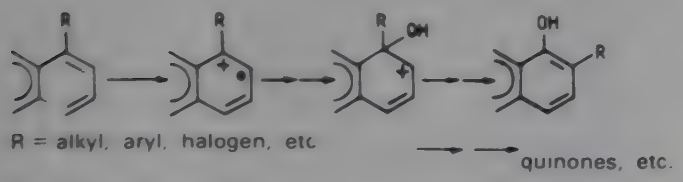
Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M V Bhatt

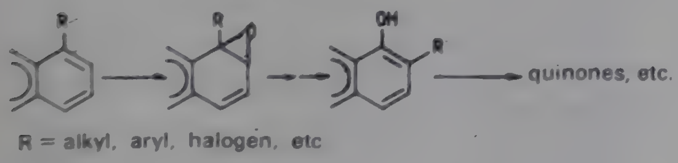
(1) Pathways in Aromatic Oxidation

Hydroxylation and oxidation of aromatic ring are reactions of chemical and biological importance. Our work involves (a) identification of some main pathways, (b) categorization of different oxidising agents according to these pathways, and (c) discovery of a 1,2-shift different from the NIH shift, occurring during oxidations which involve formation of cation ion radicals.

(A) Cation radical formation[1,2]



(B) Areneoxide formation[3,4]



(C) We believe that there are some more pathways which are yet to be delineated.

Category	Oxidising Agents
A	Fe^{III}, Co^{III}, Ni^{III} Ce^{III} Mn^{III}, HIO_4 IO_4[5,6]
B	Cr^{VI} Cr^{V} peracids

(2) Neighbouring Group Effects

A detailed study of the consequences of interaction between carbonyl function and carboxyl group and its derivatives, in close proximity, has resulted in the following generalizations:

(i) Solvent and electronic effects influence pseudo derivative formation.

(ii) No example of tautomerism between pseudo and normal forms is encountered in studies involving over 100 acid chlorides[7].

(iii) Almost all γ-keto acids lead to pseudo acid chloride formation in the absence of steric constraints. δ-Keto acids lead either to open form of acid chloride or to the formation of a mixture of the two forms, which are not interconvertible[8].

(iv) Most pseudo acid chlorides solvolyze by an S_N1 pathway, whereas the normal acid chlorides do so as a rule by S_N2 pathway[9].

(v) Evidence has been obtained for the first time that displacement of acid chlorides with nucelophiles takes place with a transition state having orthogonal geometry[8].

(vi) Factors which influence rate enhancement and geometrical factors which control keto participation have been delineated[10].

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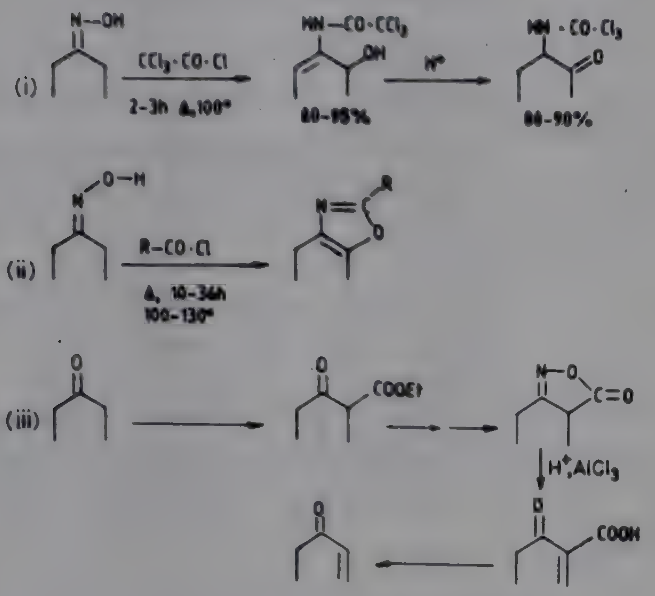
(3) Search for New Reactions

The following new, general reactions of wide synthetic utility have been discovered. Their synthetic potential needs exploration[11-13].



(4) New Reagents

(i) B-BR-9BBN[14] and AlI$_3$[15] have been developed for use as highly selective ether-cleaving agents.

(ii) Cl$_3$-SiI and Si(OAC)$_4$ have been developed for use in the cleavage of ethers and for 6-acylation and C-acylation[16].

(5) A short and technologically promising route to vitamin A has been developed[17].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

A K Bose

Bioorganic chemistry is one of the comparatively new subdisciplines of chemistry that traverses the boundaries between organic chemistry, biochemistry, newer instrumental methods (such as nuclear magnetic resonance and mass spectrometry) and a few other specialized fields of study. Through more than 200 research papers, two books, chapters in several monographs, and 7 patents, Bose has made valuable contributions to this subdiscipline as well as to synthetic chemistry.

Research on Antibiotics

Bose and his research group—including his long time colleague, Prof. Maghar Singh Manhas—are best known for important advances in the field of penicillins, cephalosporins, monobactams and other β-lactam antibiotics and related compounds. In 1966, Bose described a convenient synthesis of α-azido-β-lactams by the reaction of azidoacetyl chloride with imino compounds in the presence of an organic base. This reaction, referred to by some as the 'Bose Reaction', has proved to be a valuable synthetic approach to α-amido-β-lactams, including penicillin and cephalosporin.

In 1968, Bose and his coworkers described the total synthesis of 6-epi-penicillin and thus provided a new, stereospecific pathway to bicyclic β-lactams. By selecting a variety of cyclic imino compounds as the starting material for reaction with azidoacetyl chloride, a wide assortment of 'isopenams and isocephams' were synthesized which differed from the natural β-lactam antibiotics in having a modified bicyclic β-lactam nucleus.

The Bose Reaction is the cornerstone of the synthetic approach used by Christensen *et al.* at Merck Sharp and Dohme Research Laboratories for the total synthesis of a series of α-amido-β-lactam antibiotics and their analogs. The same reaction has been used in many other industrial research laboratories for creating new analogs of β-lactam antibiotics. Some notable examples are the synthesis of nocardicin A by Kamiya *et al.* at Fujisawa Pharmaceutical Company, monobactams by Cimarusti *et al.* at Squibb, and isocephalosporins and isopenams by Gleason *et al.* at Smith Kline Laboratories. Many academic laboratories too use the Bose Reaction to prepare interesting β-lactams. Thus, Ojima *et al.* have used this reaction to achieve asymmetric synthesis of peptides via β-lactams.

A succession of post-doctoral students—many of them from India—have worked with Bose and Manhas and developed various new techniques in the

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field of β-lactam chemistry. Taking note of the propensity of azidoacetic acid and its derivatives for explosive decomposition, an eminently practical and safe synthesis of α-amido-β-lactams was devised. This synthesis involves the replacement of azidoacetic acid with the enamine from glycine and a β-keto ester.

Bose *et al.* have paid scrupulous attention to the steric control of β-lactam formation. They have shown recently that threonine, both enantiomeric forms of which are commercially available, can be the source of either enantiomeric form of β-lactam antibiotics. The amino group of a threonine ester can be used for preparing optically active imino compounds which can then be subjected to the Bose Reaction with high enantioselectivity for β-lactam formation. Or, an aldehyde derived from D- or L-threonine can be utilized for preparing an optically active Schiff base which undergoes the Bose Reaction with complete enantiospecificity. These recent developments have provided easy access to a wide variety of optically active β-lactams which are convenient intermediates for a diversity of natural products, including amino sugars and certain types of alkaloids.

The magnitude of contribution to the field of β-lactam chemistry by the research group of Bose can be appreciated by noting that more than 80 papers in this field have been published by Bose *et al.* and manuscripts of several more publications are in preparation.

NMR Spectroscopy

Bose has made several contributions to the field of nuclear magnetic resonance spectroscopy which aid natural products chemists in structure determination. Trichloroacetylisocyanate has been shown to be a convenient *in situ* reagent for modifying the spectra of hydroxy and amino compounds. This reagent is particularly helpful in enabling interpretation of C-13 NMR spectra of steroids, terpenoids and several other families of natural products. Another useful technique described by Bose *et al.* is the use of titanium tetrachloride as an economic shift reagent for both H-1 and C-13 NMR spectroscopy of carbonyl compounds. For compounds that are not easily soluble in chloroform, arsenic trichloride has been employed as a solvent. Unlike water, chloroform and other usual NMR solvents, arsenic trichloride produces no solvent peaks in either proton or carbon-13 NMR spectra.

In collaboration with his colleague, Prof. James van der Veen, Bose has demonstrated strong, intramolecular, non-bonded attraction between aromatic groups and dipoles that significantly modify the conformation of biologically active molecules. Data from NMR spectroscopy as well as X-ray crystallography were adduced to demonstrate such conformational changes.

Mass Spectrometry

Several useful contributions to the field of chemical ionization mass spectrometry have been made by Bose and his students. In the early days of negative chemical ionization mass spectrometry, they developed the technique of using Freon 12 (dichlorodifluoromethane) as the reagent gas for obtaining chloride ion adduct anions from multi-functional compounds of low volatility; the spectra so obtained are of high sensitivity. Such spectra for oligosaccharides provide not only the molecular weight without derivatization, but the limited fragmentation observed provides information on the sequence of individual sugars in the molecule. This technique allowed the determination of the structure of a heptasaccharide antibiotic, curamycin B, using only a few milligrams of a sample.

More recently, Bose and coworkers have devised an even simpler technique for obtaining negative ion chemical ionization spectra. Their method involves the addition of a small amount of ammonium chloride to a sample placed at the tip of a solids probe. A spectacular extension of this technique has been the use of a small piece of adhesive tape that is sticky on both sides ('double-stick' Scotch tape) for the direct transfer of material from thin layer chromatography (TLC) spots to the tip of a solids probe. Very recently, this version of TLC-CIMS was used for studying complex mixtures of metabolites produced by *Penicillium icelandicum* growing on foodgrains.

In an improvement of the technique for TLC-MS, Bose and Tabei have replaced double stick Scotch tape with a 5 mg pellet of Carbowax 20M at the tip of a solids probe. Enough material can be transferred by just touching a TLC spot with the probe tip such that useful positive and negative ion chemical ionization spectra can be obtained. This method was very useful for deducing the structure of a wide array of products obtained during the oxidation of a steroid. In a further development of this technique, Bose and coworkers have ozonized *in situ* materials deposited as TLC spots and determined by the Carbowax technique the products of ozonolysis. This entire operation requires minutes instead of hours in the traditional method.

Biosynthesis and Metabolism

From the early days of organic mass spectrometry, Bose has made use of this powerful tool to aid his research in areas of natural products chemistry. He was one of the earliest to use the mass spectral fragmentation pattern of N-15 and C-13 labelled metabolites for the study of biosynthetic pathways. With his coworkers, he investigated the incorporation of stable isotope labelled amino acids into gliotoxin, phlebiarubrone and ophiobolin B and discovered some unusual aspects of their biosynthesis. In particular he and his coworkers showed that glycine, serine and some other amino acids can play an active role in the biosynthesis of isoprenoids. Utilizing a mixture of C-1 and C-2 labelled glycine, they were able to demonstrate that the classical biosynthetic pathways do not agree with the isotope incorporation pattern observed during the biosynthesis of steroids in fungi, yeast and rats.

Chemical ionization spectrometry has been used as a tool by Bose for collaborative projects with biomedical scientists. In a recent study, Bose *et al.* deduced the structure of one of the biosynthetic intermediates between cholesterol and bile acids; with only 20 μg of a sample, the entire investigation was completed satisfactorily by conducting a sequence of three separate chemical reactions and checking the change in molecular weight after each reaction. In this way, the possibility of alternative pathways from cholesterol to bile acids via bile alcohols was demonstrated. In certain rare hereditary diseases, there may be missing enzymes which block this pathway and thus elevate the level of bile alcohols produced by the liver.

Natural Products

In collaboration with Dr Ashit Ganguly of Schering-Plough Corporation, Bose and his students have determined the structure of curamycins, a family of heptasaccharide antibiotics. The structure of curamycin A was deduced on the basis of chemical reactions as well as NMR and chemical ionization mass spectral studies. For determining the structure of the minor components, curamycin B and C, negative ion CIMS proved very helpful. For deducing the details of the stereochemistry of these antibiotics, a computer aided method was developed for carbon-13 NMR spectral assignment for members of the oligosaccharide family of antibiotics. The detailed structure deduced through this approach was shown to be correct by the conversion of one of the minor antibiotics to a known natural product.

Bose has addressed himself to many other problems of bio-organic chemistry, including the nature of sex pheromones. In a study on lobsters conducted in collaboration with scientists in the Department of Fisheries in Canada, Bose *et al.* found that the sex pheromone secreted by mature female lobsters during molting is a mixture of lipophilic and hydrophilic substances.

Steroid Chemistry

Bose has developed various synthetic approaches of value to the field of steroid chemistry. He holds patents on diazosteroids and certain stereospecific modifications of steroid alcohols. He and his students have described stereospecific and chemoselective conversion of sterols to esters, ethers, halides, azides, etc. Scientists in other laboratories have been using some of these techniques extensively for the partial synthesis of steroid derivatives of biological interest.

Research in Progress

The research group of Bose is now engaged in the stereospecific synthesis of various optically active alkaloids, carbohydrates and other natural products using β-lactams as synthons.

A major new undertaking is a collabortive research programme under the title 'Bioactive Substances from the Indian Ocean'. Three Indian laboratories—the Central Drug Research Institute, the National Institute of Oceanography, and the Bose Institute—and two American laboratories—Stevens Institute of Technology and Osborn Laboratories of Marine Sciences of the New York Aquarium in America—are the participating laboratories with nearly a million dollars in PL-480 funds. Bose is the Principal Investigator on the American side; the Director of the Central Drug Research Institute is the Principal Investigator on the Indian side.

Selected Publications

Books

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Mohindra S Chadha

Chadha's first introduction to scientific research took place in 1949, when he was assigned to work for his MSc degree by the Punjab University* under the guidance of Dr S Siddiqui, Director of the then Scientific and Industrial Research Laboratory in Delhi. His day-to-day work was supervised by Dr K K Chakravarty. After finishing his work for his Master's degree, he assited Dr Siddiqui in some natural products work, as area in which he has sustained a life long interest and has made several noteworthy contributions.

After 1½ years' stay at the Malaria Institute of India in a leave vacancy, Chadha proceeded to USA to work for PhD degree at Cornell University under the guidance of Prof. John R Johnson. He completed his work for PhD degree and wrote his dissertation on the 'Biogenesis of Isoprenoid Compounds' in less than three years. To round up his academic training in the United States, he carried out two years (1955-57) of post-doctoral work under the guidance of Prof. Henry Rapoport. He was able to learn modern techniques (as were in vogue at that time) for the isolation and characterization of natural products. He carried out the synthesis of some codeine and morphine derivatives[1] and also studied the metabolism of ^{14}C labelled morphine in mice and man.

On his return from the United States of America, he worked for a brief period at the University Department of Chemical Technology, Bombay University under a May & Baker fellowship. Thereafter, he joined the Biology Division of the Atomic Energy Establishment in April 1958. The task assigned to him was to organize an organic chemistry laboratory starting from scratch. With the constraints on space and lack of any infrastructure, whatsoever, it was a frustrating task and Chadha seriously considered whether he should not go back to USA and settle there for good in a satisfying professional career. On the persuation of Dr A R Gopal-Ayengar, the then Head of Biology Division, AEET, Chadha gave up this idea and instead accepted the possibility of spending just one year in USA, as some of the requirements essential for work could be procured in the meantime.

During his return visit to the USA (1960-61), he collaborated with Prof. Jerrold Meinwald, a meticulous and ingenious organic chemist and Prof. Thomas Eisner, an eager and enterprising insect physiologist, to work on the defensive secretions of arthropods. This was an exciting experience in a new area

*After partition the Punjab University had still not found a permanent location.

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which resulted in a number of publications that have been cited extensively[2]. Back home he, along with A T Sipahimalani, characterized some C-21 steroids from the defensive secretions of some Indian water beetles[3].

The experience at Cornell University has had considerable influence on Chadha's work over the last 25 years, dealing with the chemistry of insect hormones, insect-plant interactions and insect-insect interactions. Some of this work is likely to find practical applications; important contributions are being made by him in this interdisciplinary pursuit[4].

Research activities of Chadha and his small group during 1958-67 at AEET were carried out under difficult conditions. It took nearly 10 years from the time of his joining the Atomic Energy Establishment, when a permanent abode was found at Trombay in late 1967. This coincided with the acquisition of equipment like NMR and recruitment of additional staff to give necessary impetus to his work, which had so far been carried out in makeshift laboratories, with inadequate facilities and limited staff.

From 1968 onwards, work in many interdisciplinary areas has been conducted in Chadha's laboratory. His work along with S R Udupa on the microbiological transformations of flavonoids which demonstrates a number of oxidation, reduction and hydroxylation reactions, is elegant and quite comprehensive[5]. This work has been extended to study the biotransformation of environmental pollutants and the role of fungal and microsomal systems in detoxification reactions and the mechanisms involved therein.

Another interdisciplinary area in which Chadha has made significant contributions is "Biosynthetic Potential of Plant Tissue and Cell Culture". During his work on *Plumbago zeylanica* along with M B Heble of his laboratory, he reported, perhaps for the first time, that variant cell strains with different biosynthetic activities could be separated and propagated[6]. More recently, however, work on multiple shoot cultures and cell suspension cultures in bioreactors has been undertaken with the aim of producing some of the physiologically active constituents of indigenous plant materials under *in vitro* conditions[7].

Also, success has been achieved in the regeneration of plantlets of *Tylophora asthmatica* and *Pergularia pallida* from protoplasts of the two species. Attempts will be made to bring about fusion amongst the protoplasts of the two species and to study the chemical nature of the regenerants. It is expected that the somatic hybrids may result in secondary metabolites characteristic of both the plant species or may even lead to altogether unexpected new and novel structures.

In addition to work on the isolation, characterization and biosynthesis of natural products in both *in vivo* and *in vitro* systems, Chadha along with V R Mamdapur has made notable contributions on the synthesis of prostanoids[8], jasmones[9] and several insect sex pheromones[10,11]

One of the most significant contributions that Chadha has made to the Indian scientific scene is in the area of chemical evolution and origin of life. During his stay in Berkeley as a guest scientist with Dr R M Lemmon (1961), Chadha was greatly fascinated by the work carried out by Dr Cyril Ponnamperuma, Dr R M Lemmon and Prof. M Calvin on the formation of nucleic acid bases (adenine, etc.) when an electron beam was passed through a mixture of CH_4, NH_3, H_2O and H_2. This generated a deep interest in him in primordial organic chemistry, which eventually led to a US National Research Council Senior Award to work with Dr Ponnamperuma during 1969-70 at the Ames Research Centre, NASA, California. During this period, he carried out several studies related to Jovian atmosphere and could demonstrate that amino nitriles result when electric discharge is passed through dry methane and ammonia. The amino nitriles were shown to be the precursors of amino acids and even peptides[12,13]. The role of amino nitriles in chemical evolution continues to be a topic of great interest and his work along with A S U Choughuley on this aspect is well recognized[14]. Besides work in his own laboratory, Chadha has been largely responsible for generating interest in the subject of chemical evolution and origin of life in the country. More recently, he has made serious efforts to initiate coordinated studies on the Indian precambrian rock deposits by geologists, micropaleontologists and inorganic and organic geochemists. Starting with a workshop at Hyderabad in 1978, a number of seminars and workshops have been organized and proceedings of three of these have been published[15]. As a result, excitement in this interdisciplinary area of great contemporary interest has been generated and a proposal for a national programme on "Studies Related to Chemical Evolution and Origin of Life and Co-ordinated Studies of the Indian Precambrian Rock Deposits" has been prepared and submitted to the Department of Science & Technology, Government of India, for funding. The proposed programme involves a number of institutions and scientists from different disciplines. It is expected that as a part of this programme, scientists from this country would provide some tangible answers to the all important question: How did life begin?

In summary, it can be stated that Dr Chadha has applied his training in organic and bio-organic chemistry in organizing one of the most active interdisciplinary research groups in the country bordering on the realms of chemistry and biology. This has been possible due to his own flare for working in the frontiers of bio-organic chemistry and the support he has received from a progressive organization like the Bhabha Atomic Research Centre, where the necessary infrastructure and environment for such efforts could be created.

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R N Chakravarti

Chakravarti's research career was developed in a planned manner. He started working under Prof. J C Bardhan on 1 May 1938 for his MSc of Calcutta University on the synthesis of fused ring compounds and monoterpenoids. While working for DSc in the same laboratory, he was put in charge of all other research students of Prof. Bardhan. Thus, he developed his intimacy with steroids, terpenoids and synthesis of fused rings, in addition to his interest in theories of organic nic chemistry in view of his earlier training in mathematics. During such work, he acquired sound practical skill in the preparation and handling of numerous highly poisonous and dangerously explosive chemicals with required level of confidence. He had to demonstrate his skill in this respect to others on several occasions in this country as also at Oxford, Harvard and Paris[1].

During 1944-45, he was the Chief Chemist and R&D Officer at Lister Antiseptics & Dressings Co. (1928) Ltd, Calcutta. Here he developed processes for the preparation of citral from lemongrass oil and ionones. Also, with advice from Prof. Bardhan, he prepared novoldiamine (2-amino-5-diethylaminopentane) by Leuckart reaction of novol ketone (5-diethylaminopentan-2-one) with formamide in view of the difficulties of carrying out high pressure hydrogenation-cum-amination of the latter. With its help he prepared atebrin, the noted antimalarial of those days, for the first time in this country.

During 1945-47, he worked with Sir Robert Robinson, the then President of the Royal Society, at the Dyson Perrins Laboratory of Oxford University and finalized the structure of the very complex alkaloid, strychnine. Just after this work was done, Robinson was awarded the Nobel Prize in Chemistry for 1947 and in his own account of his Nobel Prize winning work published in *Les Prix Nobel en 1947*, this work of Chakravarti received the most prominent mention. From Oxford, Chakravarti went to work with Prof. Louis F. Fieser at the Converse Memorial Laboratory of Harvard University. Here, he worked for a year on natural steroids and in September 1968, he joined the Calcutta School of Tropical Medicine as Professor of Chemistry. The main part of his original contribution was from here (for a number of years he was also Deputy Director). After 20 years, in September 1968, he took charge of Indian Institute of Experimental Medicine, under the Council of Scientific & Industrial Research, as Director. He retired from here in July 1976.

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Alkaloids

When Chakravarti started work with Robinson on strychnine, its structure was at a very critical stage of determination and a number of top grade schools were competing with one another for this. Taking up the problem, first of all a very simple method of quantitative isomerization of strychnine into neostrychnine (also brucine into neobrucine and strychnidine into neostrychnidine) was developed, by boiling strychnine in xylene solution with Raney nickel catalyst[2]. Critical studies were then carried out on the reactions of (1) bromine water and (2) nitrous acid on the neobases so obtained and thus it was ultimately possible to finally establish the very complex structure of strychnine and other members of the strychnos family[3].

Important work was done on the isolation, structure and synthesis of a new type of quinazolone alkaloid, arborine, of the plant *Glycosmis arborea*, including establishment of structure of the stable tautomeric form by comparative spectral studies of arborine and its simple analogues, 1,2-dimethyl-4-quinazolone and 2-ethyl-1-methyl-4-quinazolone, synthesized for the purpose[4]. The two synthetic analogues of arborine, as prepared in his laboratory, were later isolated elsewhere from a millipede, *Glomeris marginata*. Isolation and identification of an acridone alkaloid of the same plant, viz. arborinine, was also carried out[5]. Aegeline, originally isolated from the leaves of the plant *Aegle marmelos* and described as a sterol by (Mrs) A Chatterjee and S Bose, was established by Chakravarti as a neutral β-phenethyl amine group alkaloid by exhaustive critical studies on degradations and syntheses[6]. Considerable work on the degradations of the quaternary alkaloid, echitamine, of the bark of the plant *Alstonia scholaris* was carried out in which collaboration was available from Robinson among others. Argerine, an alkaloid related to lysergol (ergot alkaloid), was isolated from the seeds of the creepers *Argyreia speciosa* and *A.tiliaefolia* and its degradations and spectral studies were carried out.

Steroids

The earliest work of Chakravarti in connection with his MSc thesis was on the synthesis of some derivatives of bicyclo-3:0:4-nonane, similar to the C and D rings of the steroid moiety. At Harvard, with Fieser, he carried out a synthesis of α-spinasterol starting from stigmasterol, established for the first time the usefulness of lithium aluminium hydride in the reduction of steroid ketones without affecting any double bond, and simplified the procedure for the synthesis of vitamin D_3 starting from cholesterol[7].

After joining the Calcutta School of Tropical Medicine, his main interest was on finding out proper Indian plant materials for getting intermediates for the production of steroids in this country. He, along with his wife, Prof. Debi Chakravarti, who had her doctorate under Robinson at Oxford, developed the habit of plant collection by moving around different areas in the country and developed simple field-screening techniques for having interesting plants for investigation, and also maintained close connection with the forest offices throughout the country for the collection of appropriate plants in sufficient quantities. As a first step, as a pioneer worker on natural steroids in this country, he developed a simplified procedure for the isolation of sterols from plants in pure form in 1949 and isolated for the first time in this country pure stigmasterol from the plant *Enhydra fluctuans*.

In view of the importance of stigmasterol in steroid production in that period, a survey was undertaken on sterols of Indian jungle beans of the genera *Cassia, Dolichos, Lathyrus, Phaseolus* and *Vigna* by collection of the materials from all over the country. It was observed that beans of *Dolichos lablab* and *Vigna catiang* are two good Indian sources for stigmasterol comparable to soybean.

A very important and thorough survey work was undertaken in 1950 on the diosgenin content of Indian jungle yams, the dioscoreas, growing throughout the country. Yams of *D. deltoidea* of Kashmir, Punjab and Himachal Pradesh and *Dioscorea prazeri* of Darjeeling area were found to be very rich in diosgenin, a useful intermediate for the production of steroid drugs. This work was referred to in 1951 at the Medicinal Plants Symposium at the Bengal Immunity Research Institute, Calcutta, and in 1952 at the Hormone Symposium at the Central Drug Research Institute, Lucknow and these yams were strongly recommended for proper utilization in starting Indian steroid industry with Indian raw materials in a detailed publication[8].

The first step in the conversion of a steroid sapogenin into any of the useful steroid hormones, involving high pressure reaction at an elevated temperature for conversion into the pseudosapogenin, was simplified by carrying out the reaction in a high-boiling solvent like triacetin[9]. Useful microbiological transformation of diosgenin into epismilagenin and smilagenone[10] opened up a path for further useful studies in this area. The effect of Raney nickel on steroids and triterpenoids in high boiling solvents was studied exhaustively[11–13]. In both types, dehydrogenation (oxidation) of 3α- or 3β-OH and hydrogenation (saturation) of easily reducible double bond were observed, in addition to isomerization of 5 β-hydrogen to 5α- and dimerization in the case of steroids, and shifting of the double bond to an adjacent position, as in allylic shift in the case of triterpenoids.

In addition to establishing the Indian dioscoreas as raw materials for starting an Indian steroid industry, he continued further work for finding out other suitable Indian sources for the purpose. It was observed that hecogenin of Indian agave plants as also of wastes of Indian sisal fibre industries are not suitable for the purpose in view of low yields and their occurrence in admixture with tigogenin. Work on *Solanum khasianum* was initiated by him along with his student, P C Maiti, who later completed the investigation elsewhere and observed its seed coat to be rich in solasodine, as alkaloidal steroid sapogenin suitable for use as a steroid intermediate similar to diosgenin. The chief difficulty is about collection of the plant material. Also, B Dasgupta of his steroid group, later working elsewhere, found fair amounts of diosgenin in rhizomes of *Costus speciosus*. The main difficulty in this case is economic separation of diosgenin from the crude mixture of sapogenins. All these cases were subsequently studied for practical utilization by Chakravarti on comparative basis by collection of these from different areas.

During one of his later field screening operations, he came across an exotic weed, *Kallstroemia pubescens*, seeds of which possibly came here with PL-480 foodgrains; the plant is now growing luxuriantly around Calcutta and elsewhere. This very fragile and rapid growing weed has been found to have high diosgenin content[14]. Passing mention may be made of the isolation of and work on yuccagenin of *Cestrum nocturnum*, tigogenin and ursolic acid of *Cestrum diurnum*, α-spinasterol of *Albizzia lucida*, etc.

Terpenoids

Exhaustive work was carried out on the very interesting camphorquinone and santenonequinone rearrangements in the presence of conc. sulphuric acid involving both degradative and synthetic work. A synthesis of allosantenic acid and, in connection with degradative work on sesquiterpenes, a synthesis of eudalene, were carried out. Considerable degradative work was carried out on andrographolide, a diterpene lactone of *Andrographis paniculata*. A number of new triterpenes, e.g. gymnemagenin, cadambagenic acid, marsileagenin, etc. were isolated from various plants and degradative work for the determination of their structures was carried out. A detailed study was made on the action of Raney nickel on numerous triterpenoids, isolated by his team over the years from various plants; the main results have already been mentioned under 'Steroids'[13].

Effect of Substituents on the Course of Cyclizations

After a critical study of the course of a large number of Dieckmann cyclizations reported in a series of papers[15], generalized rules were chalked out for predicting the course of such cyclizations based on the comparative electrochemical properties of adjacent substituents. As a result of such generalisations, it was possible to satisfactorily explain the mechanism of a number of hitherto inexplicable paradoxical cases of other workers in different laboratories.

Argemone Poisoning and Tri-ortho-Cresyl Phosphate Poisoning

Earlier, there were frequent outbreaks of the epidemic dropsy, involving glaucoma, weakening of heart and death through ingestion of cooking oils contaminated with argemone oil obtained from the seeds of *Argemone mexicana* containing the highly toxic alkaloid, sanguinarine. In 1950, Chakravarti developed a very simple hydrochloric acid test[16] for the detection of such contamination. The test was made highly specific and sensitive by him as a chromatographic-cum-fluorescence spot test. This test is currently used as a routine test in public health and food testing laboratories throughout the country. There was a sudden outbreak of a paralytic disease in 1962 in which about 600 people suffered in Malda district of West Bengal and Darrang district of Assam. It was established to have originated from contamination of imported wheat flour with tri-o-cresyl phosphate. Though there were numerous earlier and later cases, throughout the world, of people in large numbers suffering like this through the intake of cooking oils and drinks contaminated with TOCP, this was the first case of such contamination through solid foodstuff. A standardized method was developed for the detection of such contamination, which has proved to be useful in later cases.

Cultivation of Medicinal Plants

Chakravarti made valuable contributions at the Rongo Plantation of Medicinal Plants Scheme of the Government of West Bengal by working on chemical aspects for its proper development. The most successful work here was cultivation of ipecac, as a result of which import of ipecac roots was stopped and manufacture of emetine was started in this country. He also developed the laboratory model of equipment for the production of camphor from *Ocimum kilimandscharicum* and set up a pilot plant at Rongo (near Darjeeling) for the purpose.

Among others, particular mention may be made of his synthetic work[17] with Prof. N P Buu-Hoi on complex coumarins of biological interest carried out in 1958 at the Institut du Radium, Paris.

In addition to help from his numerous students and colleagues, he got immense help from his wife, Prof. Devi Chakravarti.

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Animesh Chakravorty

The chemistry of transition elements is replete with fascinatingly diverse patterns of structure and reactivity. It has wide interfaces with organic synthesis, industry and biology. We have been fortunate to be in such chemistry. The salient features of our activities during the last 10 years (1975-1984) are given below, followed by a very brief statement on the earlier work (1959-1974).

The focus of our recent activities has been oxidation state sequences, electron transfer reactions and redox chemistry. Synthesis of new molecules and their structure determination are essential prerequisites for this endeavour. A variety of tools, including single crystal X-ray diffractometry, are used. Modern electrochemical techniques have been used systematically and extensively for the first time in India in structure-reactivity type inorganic chemical research.

Several years ago, we demonstrated that amine-imine-oxime type donors afford model nickel species in high (+3, +4) oxidation states. These undergo facile electroprotic equilibria involving one-electron or two-electron steps. These reagents, which are now being used by several other groups in mechanistic studies, have assumed special significance with the recent discovery that higher oxidation states of nickel are important in biology. We have now been able to attach such states to polymer-modified graphite surfaces and to examine their electroprotic reactions. The first example of a discrete $Ni(III)O_6$ coordination sphere has just been discovered.

Molybdenum and copper are well-known redox-active bioelements. This attracted us towards their chemistry. We mention the design of the species MoO_2 (tridentate) which has one active site and binds many monodentate ligands (substrates). Such species undergo oxygen transfer from the MoO_2 group to bound substrates. Monomeric high-potential CuN_4 species have been generated using π-accepting donors. The redox properties of strongly exchange-coupled dimers and trimers of copper have been of special interest. Groups of trimers having one unpaired electron have been designed. The unique electron can be electrochemically ionized, affording novel valence-delocalized triangular species with metal oxidation number of +2.33. Such species are under active study by us and others.

The chemistry of platinum metals has been dear to us. The arylazopyridines and arylazooximes are excellent σ-donors and π-acceptors, particularly towards ruthenium and osmium. The complexes display isomerism, stereodynamism (due to substitution or deprotonation) and complete electron transfer series (up to seven steps). The above noted π-accepting

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power raises the metal redox potentials and it has been possible to catalyse the oxidation of water to dioxygen with the help of ruthenium-azopyridine chelates which sustain the active two-electron two-proton shuttle Ru(IV) O-Ru(II)OH_2. Electrophilic addition of ruthenium nitrosyls to activated methylene functions has afforded new chelates. Stabilization of the +4 state of ruthenium has been achieved with triazene .1-oxides. Hydroxamates afford dimers which display two successive Ru(III)-RU(II) couples whose potential separation can be modulated by the length and nature of the bridging group. Tris thiohydroxamates are unique in showing successive reversible electron transfer steps involving the +3, +4 and the very rare +5 states of ruthenium. Spontaneous formation of Ru-C bonds occurs in the reaction of ruthenium salts with alkylthio substituted azobenzenes. Ruthenium chemistry is full of excitement.

Correlative studies of redox properties with other molecular parameters have engaged us. These include effects due to ligand fields, substituent polarity and stereochemistry. The correlation of IMCT transition energies with metal oxidation and ligand reduction potentials in large groups of ruthenium (II) species has been noted. The symbiotic relationship of electron transfer and proton transfer has been explored, affording novel examples of electroprotic equilibria in aqueous solution. At times, an electron transfer pathway can be blocked by protic manipulation, as in the case of molybdenum hydroximates.

A reaction of very special interest to us is aromatic hydroxylation—a reaction that is quite important in both chemistry and biology. The oxidation of CH to COH has been achieved in copper, cobalt, palladium and platinum coordinated arylazopyridines. Dioxygen, hydrogen peroxide and peracids can be used as oxidants. In *ortho*-metallated square planar chelates of palladium and platinum, we have shown that the MC bond can be selectively oxidised to MOC by peracids in high yields. In this novel reaction, a metal-peracid complex is initially formed and a rational mechanism of hydroxylation can be devised. An unique reaction in which an oxime oxygen atom thermally and intramolecularly migrates to hydroxylate an aromatic ring in platinum arylazooximates has been discovered. This chemistry is full of surprises.

Turning to our earlier work (1959-74), we recall the fabrication of a microspectrophotometer and its use in the study of polarized spectra of metal chelates in the laboratory of Prof. Sadhan Basu (1958-61). This type of activity which among other things revealed the first example of trigonal splitting in tris chelate [$Cr(acac)_3$] was new in India. This was followed by independent ventures, such as the first assignment of the charge transfer spectra of a square planar complex ($AuCl^-_4$). At MIT and Harvard (1961-64), several kinds of studies were done with Profs. F A Cotton and R H Holm. Particular mention is made of NMR contact shift studies of paramagnetic complexes. At the Indian Institute of Technology, Kanpur (1964-77), we primarily dealt with the stereochemistry of tris chelates, pentacoordination via the M (bidentate) (tridentate) strategy, coordination by aromatic halo groups, thermodynamics of stereochemical equilibria and magnetic exchange. We got into the problem of higher oxidation states of nickel around 1974 and this gradually led to a certain change in our outlook. We tilted more towards reaction studies and redox chemistry. The power of modern electrochemical techniques was recognized and the construction of a cyclic voltammeter was successfully completed. Chemistry moved on and we tried to move with it. There was also a physical movement from the Indian Institute of Technology, Kanpur to the Indian Association for the Cultivation of Science, Calcutta, in 1977.

Throughout my career, I have been very fortunate to have outstanding teachers, helpful colleagues and many dedicated students. My indebtedness to them cannot be counted in words. Financial support received from DST, DAE and CSIR is gratefully acknowledged.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

J N Chatterjea

Chatterjea's major contribution has been in the field of oxygen heterocycles in relation to natural products which include condensed benzofurans, condensed chromenes, isochromenes, flavans and homoisoflavones.

Original methods, some of them novel, were devised for the synthesis of condensed benzofurans, such as brazans (related to natural products or coal tar derivatives) and the related quinones[1]. A direct one-step synthesis of dibenzofurans could be brought about from cyclohexan-1,3-diones; further elaboration of the products by ring annelation led to a wide variety of heterocycles[2]. A direct outcome of the above investigation was the study on the acylation of isocoumaranones under base-catalysed conditions or by NN′-diarylamidines, whereby the related anils were secured directly. Facile acyl-lactone rearrangement of the products and the transformations of some intermediates led to a range of interesting products and revision of some erroneous structures[3].

Short and efficient synthesis of coumestans (now known as Chatterjea-Kawase synthesis[4]) has been carried out leading to coumestrol, iso- and dihydropsoralidene, tri-O-methylwedelolactone, dihydroerosnin, etc.

A practical method of synthesis of 1,2-chromenes from coumarins was worked out and an application of the method was the synthesis of O-trimethylhydrobrazilin from the related indenocoumarin[5] Hydroboration-peroxide oxidation of the former led to (±) O-trimethylbrazilin. A synthesis of 3,4-dehydrohomopterocarpin (now a natural product) was similarly patterned from O-dimethylcoumestrol and converted to (±) dihydrohomopterocarpin and (±) homopterocarpin. The isomeric 2,3-dehydrohomopterocarpin or a 3-arylcoumarin is obtained on dehydrogenation of the natural product[6]. The latter arises from a deep-seated rearrangement by way of intermediacy of radicals, while the oxidation of the former to O-dimethylcoumestrol gave the first unequivocal proof of the tetracyclic nature of homopterocarpin.

Coumarino (3′,4′-2,3) coumarones (isocoumestans) have been successfully transformed into compounds having semblance with pterocarpins. A synthesis of isocoumestans involving Wanzlick oxidation with 3-hydroxycoumarin was achieved[7].

The first synthesis of isochromene, an unstable and elusive compound, was devised[8]. The method is flexible, but its adaptation in the area of natural isochromenes proved difficult. A number of natural isocoumarins, such as O-methylkigelin, *cis-* and *trans*-artemedins,

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O-methylglomellin, O-dimethylreticulol, oospolactone, etc., were synthesized, confirming their assigned structures. Some new methods for the synthesis of 3-alkylisocoumarins were developed[9]; as many natural isocoumarins bear a variable side chain at the 3-position, their syntheses are amenable to effective manipulation of the alkyl group.

The above studies led to the following results of exceptional interest:

(i) Discovery of cases of *trans*-alkylations involving aromatic alkoxyl groups[10]. The alkylations involve esterification and N-alkylation. The phenomenon is also noted in thio-isocoumarins and isocarbostyrils.

(ii) Base-catalysed fragmentation-cum-ring contraction in some isocoumarins with certain structural features[11].

(iii) Base-catalysed ring-expansions in indan-1-ones substituted in the 5-membered ring by nitrosation giving 2-hydroxyisocarbostyrils[12].

(iv) Formation of pyrocollines during reactions of isochromandiones with dichloronaphthoquinone in pyridine[13]. Some natural product derivatives behave similarly when the structural features are parallel.

Oxoindenocoumarins and indenoisocoumarins were encountered during studies on Stobbe condensations with homophthalic esters. Independent syntheses of the compounds opened up new vistas (formation of dibenztropones, etc.). A novel synthesis of unsymmetrical dicyanostilbenes was carried out and a neat synthesis of oxoindenocoumarins achieved[14].

In the course of the synthesis of naturally occurring 4-arylchromenes (kuhlmanene group) from β-phenoxy ethyl aryl ketones, the occurrence of retro-Michael reaction and recombination was noted, leading to O → C migrations. In consonance with this observation, Mannich bases were condensed with phenols giving adducts at the *para* position to the phenolic-OH group and leading to β-4-hydroxyphenylethyl aryl ketones. These undergo rearrangement[15] under oxidative conditions to give benzopyrylium salts, such as O-trimethylapigenidin chloride, O-tetramethylluteolinidin chloride, etc. It is postulated that a double 1,2-shift occurs—the driving force being the formation of the aromatic pyrylium system. The researches in this area were interrupted and further investigation in this area is called for.

With the synthesis of anhydrobrazilic acid from iso-anhydrobrazilic acid by Raney nickel induced isomerization, the first synthesis of homoisoflavone was carried out[16]. The synthesis of (±) di-O-methyleucomol was brought about by a new method involving an internal Hoesch condensation of a cyanhydrin at the ultimate stage.

Selected Publications

1. Chatterjea J N, Experiments on the syntheses of furano compounds. Part III. A new synthesis of β-brazan. Synthesis of Kostanecki's 3-methoxy-, 3,8,9-trimethoxy- and 3,4,8,9-tetramethoxy-β-brazanquinone, *J Indian chem Soc*, **31** (1954) 101; *Experientia*, **7** (1951) 374; **9** (1953) 256; Synthesis of α-brazan and the related quinone, *Experientia*, **12** (1956) 18.
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Asima Chatterjee

Chatterjee's research activities have extended over a period of 48 years. Her major interest lies in the chemistry of natural products derived from Indian medicinal plants with special reference to structure, stereochemistry and synthesis. She has made significant contributions in diverse classes of natural products of which alkaloids, polyphenolics and terpenoids deserve special mention. Besides her keen interest in fundamental research, she always laid stress on the utilization of phytochemicals from indigenous plants as drugs, drug intermediates and other compounds of economic importance. Her more important scientific achievements are outlined in the sequel.

Indole Alkaloids

Chatterjee is well known for her research on the chemistry of indole alkaloids—a field in which she evinced keen interest since the beginning of her research career when she initiated research on the alkaloids of *Rauwolfia canescens*. Her interest in this field received further impetus while working with Professor Paul Karrer N L, at Zürich University (1949-50) on corynantheine and related problems. Subsequently, she extended her investigation to different *Rauwolfia* species and other genera of Apocynaceae. Her pioneering work on the alkaloids of *Rauwolfia*, *Vinca*, *Alstonia*, *Rhazya* and *Kopsia* had considerable impact on the subsequent research in the field of indole alkaloids in India and abroad. Some of the alkaloidal constituents occurring in these genera are used in modern medicine. Chatterjee and her associates have investigated the chemistry of almost all the principal types of indole alkaloids known to date. This includes, in addition to several bisindoles of novel structures, the monomeric C_{19}-C_{20} indolic bases of the corynantheinoid, yohimbinoid, heteroyohimbinoid, strychnos, sarpagine-ajmaline, vobasine, picraline and aspidosperma types. Among her earlier work in the area, mention may be made of the studies on the structure and stereochemistry of rauwolscine (α-yohimbine), the major alkaloid of *Rauwolfia canescens*. It not only revealed the occurrence of yohimbinoid bases in *Rauwolfia* species, but was also useful in elucidating the structure of reserpine and other related alkaloids of Rauwolfia. She also made notable contributions in regard to the elucidation of the structure and stereochemistry of ajmaline and sarpagine. The correct stereoconfiguration of the latter was first suggested by her group.

One of the most fruitful areas of her research, in which work is still continuing, has been the investigation of various

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Alstonia species. More than 20 new alkaloids have been isolated from *Alstonia venenata*.

Extensive studies on echitamine, a quaternary alkaloid of *Alstonia scholaris*, established the presence of a pyrrolidino-indoline moiety in the compound. One of the most challenging problems has been her work on the structure of the alkaloid nareline isolated from *A. scholaris*. It possesses a novel skeletal pattern (indolo-2-aza-adamantane incorporating a homotropane moiety) and is biogenetically derived from the picraline-type bases. It features a modified E-ring with a C-6—C-21 rather than the usual N-4 – C-5 bond. The exocyclic C-5 is present as an aldehyde group, which forms a cyclic hemiacetal with a hydroxyl attached to N-4. The elucidation of the structure of this alkaloid and study of its chemistry have opened up a new chapter in indole chemistry.

Her work on *Alstonia macrophylla* is highlighted by investigations on the chemistry of the dimeric alkaloids—villalstonine, macralstonine and macralstonidine, and the structures of the monomeric O-benzoyl-vincamajine.

Her research on *Rhazya stricta* has been acclaimed widely, viz. her work on the alkaloids of the aspidospermine type (rhazidine), the sarpagine skeleton (rhazine), the picraline series (strictamine and rhazinaline) and the tetrahydrocarboline compound (rhazinine).

Chatterjee and her associates have made extensive investigation on the alkaloids of *Voacanga grandifolia*. The most important contribution has been her work on the novel bis-indole alkaloid grandifoline and a number of its congeners. Grandifoline possesses an isovobtusine stereochemistry at the spiro carbon 14 (R configuration) and an oxide bridge flanked between C-2′ and C-3.

From *Rauwolfia reflexa*, several new monomeric and dimeric indole alkaloids have been isolated. Among these, the red dimeric base flexicorine exhibiting a novel structural pattern deserves special mention. This alkaloid was shown to be a 10′-hydroxy-Na-unsubstituted indoline which preferentially existed in the oxidised iminoquinone form, hitherto unknown in indole chemistry.

In connection with her work on indole alkaloids, Chatterjee has published a number of papers concerning their biogenesis. Notable in this connection was the isolation and characterization of geissoschizine, a key intermediate in the biosynthesis of indolic bases from *Rhazya stricta* from her laboratory. Another interesting observation was the occurrence of venoterpine, a monoterpenoid pyridine base from *Alstonia venenata and Vinca major*. The cooccurrence of this monoterpenoid pyridine base with C_{19}-C_{20} indole alkaloids provides evidence in favour of the currently accepted biogenetic theory.

Her work on indole alkaloids also includes investigation on *Kopsia fruticosa* and *K.arborea*, the β-carboline alkaloids of *Perganum harmala*, the 2-acylindole bases of *Tabernaemontana sphaerocarpa*, the indoloquinolizidine alkaloids of *Zanthoxylum* species and the alkaloidal constituents of *Vinca pusilla, V. rosea, V. major* and *Strychnos nuxvomica*. She has also made valuable contributions—mechanistic, stereochemical as well as on the transformation and correlation studies of a number of indole alkaloids. These include conversion of yohimbinoid alkaloids to their corresponding 3,4-seco derivatives, studies on the stereochemical course of ketone reduction in yohimbone and rauwolscone with different reagents. New and novel chemistry has evolved from her investigations on the enol-ether system of the heteroyohimbinoid alkaloid ajmalicine (isolated from *Catharanthus roseus*). Her study of the intriguing stereochemical problems arising from the isolation of several labile reaction products of ajmalicine with mineral acids is noteworthy.

The conversion of the inactive oxindole base mitraphylline (the major constituent of *Mitragyna parvifolia*) to the biologically active base, ajmalicine, with the retention of the chirality of the molecule at C-3 is a significant achievement in indole chemistry.

A novel synthesis of the pentacyclic indole alkaloid (±) decarbomethoxydihydrogambirtanine, occurring in *Ochrosia lifuna* and *Ochrosia miana*, provides a simple and general method for the synthesis of indole alkaloids with the desired chirality and having the yohimbinoid skeleton. The key synthon was prepared from the appropriate 2-indanone. This synthesis shows her ingenuity and reflects an entirely new strategy.

Other Alkaloids

Besides indoles, Chatterjee has made significant contributions to the chemistry of steroidal alkaloids, particularly the new and interesting 5 α-pregnane derivatives, viz. chonemorphine and related alkaloids isolated from Apocyanaceae and Buxaceae families. Special mention may be made of japindine, an unusual dimeric steroid alkaloid of *Chonemorpha macrophylla* incorporating a thiourea linkage and the C- nor D-homo steroidal base kashmirine, isolated from *Fritillaria roylei* (Liliaceae) bearing a *cis*-D/E ring juncture, which was hitherto unknown in this class of compounds. The structure and stereochemistry of saracocine, saracodine, saracodinine and the alkaloids A and B, all having a 5 α-pregnane skeleton deserve mention.

Chatterjee has done considerable work on new alkamides from *Piper longum*, *Pleiospermum alatum* and *Aegle marmelos* and the α-pyridine alkaloids of *Trewia nudiflora*. The new aporphine alkaloid sparsiflorine and its biogenetic precursor, the isoquinoline spirodienone crotoflorine, have been obtained from *Croton sparsiflorus*. Synthetic studies on a number of quinoline and isoquinoline alkaloids were also carried out. In this connection, a simplified and novel procedure for the preparation of the required β-phenylethanolamines was developed. Attention was also given to the synthesis of these alkaloids under physiological conditions. The syntheses of calycotamine, pseudocodamine and pseudolaudanine may be mentioned in this connection.

Significant is the novel and new approach developed by her for the syntheses of the naturally occurring tetrahydroberberine alkaloids, (±)-2,3-dimethoxy berbine and (±) norcoralydine. The strategy developed is simpler than the previously reported methods. In this method, a suitable 'D' ring is chosen on which the 'C' is developed. This bicyclic C/D ring system is then cleaved by condensing with a suitable A/B unit, so that an overall A/B seco C/D ring is obtained. The seco 'C' ring is converted to the desired cyclic form. In connection with the synthesis of (±)-norcoralydine, it is worth mentioning that the synthesis of 5,6-dimethoxy-2-indanone was achieved by a unique diazoketone cyclization procedure. In contrast to previous observations, this is a very useful synthetic route to the formation of substituted 2-indanones.

Terpenoids

Chatterjee's contributions in the field of terpenoids once again reflect her varied interest and knowledge in other groups of natural products. Her studies on *Aphanamixis polystachya, Walsura, tabulata* and *Cedrela toona* (all Meliaceae), *Zanthoxylum rhetsa* (Rutaceae), *Artemisia vulgaris* (Compositae), *Croton caudatus* (Euphorbiaceae) and *Callicarpa macrophylla* (Verbenaceae) deserve special mention.

The two furanoid norditerpenes of the rearranged labdane series, crotocaudin and isocrotocaudin, from *Croton caudatus*, constitute a novel diastereomeric pair of furanoid norditerpenes of complex structural pattern. The isolation of the diterpenes is also important, since *Croton* species are generally known to produce proaporphine and aporphine alkaloids. Among her other contributions to the chemistry of new terpenoids, mention may be made of the pentacyclic triterpene alcohol fernenol (fernane skeleton) (*Artemisia vulgaris*), the pentacyclic triterpenoid ketone xanthoxylone of the β-amyrone skeleton (*Zanthoxylum rhetsa*), the diterpenes calliterpenone and calliterpenone-17-acetate from *Callicarpa macrophylla*. Studies on aphanamixin, a tetranortriterpene featuring a 5-membered hemiacetal with an α-oxirane system and aphanamixinin, a ring B seco-triterpene from *Aphanamixis polystachya*, the pentacyclic triterpene walsurenol (*Walsura tabulata*) and the tetranortriterpenes swietenine (*Swietenia macrophylla*) and tinosporine (*Tinospora cordifolia*) have revealed several novel features in the chemistry of tetranortriterpenes.

She has also done significant work on the backbone rearrangement of terpenoids. Her novel work on the correlation of terpenoids of different skeleta through Lewis acid catalysed rearrangements led to a better understanding of their structural relationship.

The interesting partial syntheses of glochidone and 2-methoxycarbonyl-A-nor-lupane, olean-9(11), 12-diene-3-one and ursan-9(11),12-diene-3-one (≡ marstormosanone) have been achieved from readily available starting materials.

Coumarins and Other Polyphenolics

Another class of compounds on which Chatterjee has made outstanding contribution is the coumarins. A significant number of coumarins bearing interesting substitution patterns have been isolated in her laboratory from Indian medicinal plants belonging to the families Rutaceae, Umbelliferae, Compositae, Euphorbiaceae and Thymelaeaceae. These show greater modification of the isoprenoid moiety than any other class of natural products.

Her research in this field began with the elucidation of the structure of luvangetin isolated from *Luvanga scandens* (Rutaceae). Special mention may be made of her work on *Aegle marmelos* and *Prangos pabularia*. Her work on the oxidative elimination of isopropanol side chains substituted at the α-carbon of dihydrofurocoumarin systems with DDQ is of considerable biogenetic importance.

It has been observed by her that γ,γ-dimethylallyl ethers of hydroxycoumarins when subjected to the conditions of Claisen rearrangement suffered degradation to phenolic coumarins and isoprene instead of undergoing any molecular rearrangement.

Chatterjee's synthetic studies on the reactions and rearrangements of prenyl and prenyloxy coumarins using different Lewis acids deserve special mention. This research has resulted not only in the synthesis of naturally occurring coumarins bearing unconventional substitution patterns, but also in the discovery of new reactions. The work carried out shows how such interconversions can provide a unique basis for the correlation of various types of natural products besides making significant contributions to the understanding of their biogenetic pathways. In a way, her studies can be considered as a bridging link between structural and synthetic organic chemistry. She also developed new syntheses of the 4-phenyl coumarins, dalbergin and nordalbergin, and of coumarin and its derivatives.

Chatterjee has also contributed to the chemistry of other polyphenolics. The plant pigments cassianin and siameanin, obtained from *Cassia siamea*, possess dimeric structures and are biogenetically derived by the phenol-coupling of hydroxylated anthraquinone moieties. Also worthy of note is her work on the revision of the structures of the flavones tambulin and tambulol, isolated from *Zanthoxylum* species. Other contributions on polyphenolics include her studies on the structure and synthesis of the interesting lignans of *Machilus edulis* and *Jatropha gossypifolia*, the flavonoid glycoside, vogelin (*Polygonum recumbens*), the chalcones of *Piper methysticum* and *Flemingia chappar*, and the flavanone archangelenone and the biogenetically related benzo-γ-pyrone, angelicin from *Angelica archangelica*.

Miscellaneous Studies

Mechanistic and synthetic studies also constitute other areas of her research activities. The mechanism of the acid-catalysed hydramine fission of β-phenylethanol amines has been investigated in detail. It was observed during these studies that the substituents on the aromatic rings play an important role in determining the nature of the products and steering the course of the reaction. This work has been incorporated (*page 705*) in the internationally acclaimed text book *Organic Chemistry*, Vol. II, by I L Finar (Longman Group Ltd) for undergraduate and postgraduate students. She introduced the use of periodic acid as a reagent for the detection and location of both terminal and exocyclic double bonds in organic compounds. The first successful reduction of N-formylindoles, prepared by the Duff and Vilsmeier-Haack reactions, to N-methylindoles, was achieved by the use of diborane. In this reduction, 3-methyl-1-formylindoles also afforded 1,3-dimethyl-3-(3′-methylindolyl-1′-methyl) indoline—an observation providing further evidence in support of the present mechanistic theory that the electrophilic substitution of 3-substituted indoles occurs primarily at the 3-position followed by the migration of one of the substituents at C-2, depending on its migratory aptitude. She has also studied the mechanism of the Dakin reaction with differently substituted aromatic aldehydes.

In connection with model studies on alkaloid synthesis, it was observed by her that the reaction of *p*-anisylanthranilic acid with formamide gave, instead of the reported quinazolone, the dihydro derivative. The formation of trimeric and tetrameric products from anthranilic acid featuring a 1,5-diazocine ring system was observed during the synthesis of deoxyvascinone.

Chatterjee's contribution on the electrophilic substitution reactions of indoles with carbonyl compounds and iminium systems catalysed by Lewis acids has received considerable recognition. This has culminated not only in the synthesis of novel indole systems but also in the discovery of new reactions and rearrangements. Her work in this area has shed new light on the mechanistic pathway to the electrophilic substitution of indoles.

An industrial method of preparation of indigo from indole-3-aldehyde by the application of Dakin reaction has been developed. Her work on provitamin A activity of some stereoisomeric cryptoxanthins is important.

Chatterjee's interest in the cryptogams, specially the Indian ferns, is also noteworthy. Several water ferns belonging to the family Marsiliaceae, particularly *Marsilea* and related species, were examined. *Marsilea minuta* (≡ *M.quadrifolia*) as well as *M.rajasthanensis* were found to contain a sedative and antiepileptic (anticonvulsant) drug, marsilin, whose structure has been established. A combination of marsilin with another herbal to accentuate its activity has already been introduced as a rehabilitation and antiepileptic drug under the name Ayush-56 (patented). An antimalarial medicine (Ayush-64) which is a combination of four medicinal herbs has already been developed. This medicine has been shown to possess both preventive and curative properties in malaria (*Plasmodium malariae* and *Plasmodium vivax*). Know-how for both Ayush-56 and Ayush-64 has been purchased by NRDC, Government of India, and these are available in the market. Among her other research contributions of biological interest was the isolation of the glucoside, neridin, along with its aglucone, plumericin, from *Nerium indicum*. The former has been shown to be an important "adaptogen" (a drug which provides nonspecific resistance to diseases).

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Mihir Chowdhury

The contributions of Chowdhury and his collaborators in the area of molecular photophysics are briefly summarized below.

(1) Radiative Transition (or Photon-Molecule Interaction)

As is well known, the most important term in photon-molecule interaction is the scalar product of the electric field of light and the transitory electric dipole moment of the molecule. The investigations on polarized single crystal spectra at 4°K or above by the group have established the direction of the electric dipole transition moment in a number of cases. This has led to the assignments of various electronic states, such as C-T states, $(n\text{-}\pi^*)$ states of polyfunctional molecules (e.g. aromatic azines, triketoindane, alloxan, thiobenzophenone), and crystal field (CF)-split electronic and vibronic states of transition metal and lanthanide ions. A few interesting cases may be cited. It was shown by means of the photo-selection technique that the charge-transfer bands in organic molecular complexes are polarized perpendicular to the molecular stacking plane[1]. The pioneering study of the relative intensities of three Zeeman components of S-T absorption in organic single crystals threw new light on spin-orbit coupling in investigated molecules. They generated transitory (pulsed) high magnetic field (~200 kG) and used it to study optical Zeeman effect in pure and doped single crystals, which led to the evaluation of g-values of many excited states[2]. A case of inducting transition probability into a forbidden transition through magnetic perturbation was noted for Pr : DG[3]. Another interesting system investigated was the centro-symmetric series of Ln^3(HAPI) single crystals, which proved to be ideal for studying vibronic bands associated with Ln^{3+}-transitions.

The next important part in photon-molecule interaction is the magnetic dipolar transition moment. Its relatively small contribution in lanthanide and other systems has been measured for cases (i) where the electric dipole transition moment is intrinsically small, as in Eu^{3+} $^7F_0 \rightarrow {}^5D_1$ transition and (ii) where the electric dipole transition moment is forbidden by the g-g solution rule because of the presence of a centre of symmetry[4]. The investigators obtained, for the first time, high-resolution circular dichroism spectra of single crystals of lanthanide complexes and exploited them extensively to find out magnetic dipolar contributions to CF-split component-to-component transitions in lanthanides[5]. CD studies of cubic (LnDG) and trigonal (Ln-DG, Ln-PG) single crystals and comparison with

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powder spectrum have yielded information on quadrupolar or higher-than-quadrupolar transition moments in these systems. A method for calculating the chiro-optical behaviours of lanthanide complexes has been developed. The MORD/MCD has also been studied for a few cases.

The non-linear contributions to the photon-molecule interaction have been explored recently through two-photon spectroscopy[6] and resonance second harmonic generation[7], taking advantage of the high peak intensity of the pulses from the NPLD laser. The differences in one- and two-photon selection rules have been exploited to identify the g-states in bimolecules, such as *trans*-dimer of acenaphthylene, dihydroanthracene and trypticene and to sort out $\triangle J \geqslant 2$ transitions from $\triangle J = 1$ transitions in Ln^{3+} systems. The possibility of intensity-dependent CD was predicted[8], although experimental demonstration of the effect is still lacking.

Other works of the investigators in the area of molecular energy levels include a new theoretical technique for CNDO-MO parameter evaluation[9] and a new method for open-shell LCAO-MO-SCF calculation.

(2) Non-Radiative Transition (or Phonon-Electron Interaction)

The understanding of phonon-molecule interaction is poorer at present in comparison with our knowledge of photon-molecule interaction. Nevertheless, some generalizations within a class of molecules have appeared from time to time. One such generalization is Kasha's rule that the non-radiative decay rate of a $^1(n,\pi^*)$ state is much higher than the radiative decay rate, resulting in the absence of any reports of $^1(n,\pi^*)$ fluorescence. The first exception to this rule was noted by Chowdhury in tetrazine. Subsequently, a few other exceptions, such as pyridazino-pyrazine, triketoindane, etc. were discovered.

Another widely accepted generalization is that only the lowest states of organic molecules in condensed phase fluoresce. However, S_2-fluorescence from dipheyl-s-tetrazine has been noticed by the investigators and explanations have been offered for these anomalous fluorescences[10].

In contrast to the strong electron-phonon coupling in organic molecules, the environmental effect on electronic states is small for lanthanides. Lanthanides were, therefore, chosen as a model system for the study of the role of electronic symmetry in the non-radiative processes. The group was able to establish the point that in Eu-DG single crystal, a direct channel from $^5D_2$ to ^5D_o exists, bypassing $^5D_1$[11]. Ray and Chowdhury have developed a general theory for non-radiative transition rates in lanthanide ions embedded in solid matrices[12]. Their investigations on the influence of magnetic field on ISC processes are discussed in the next section.

Apart from internal conversion (IC) and intersystem crossing (ISC) processes, Chowdhury and collaborators are involved in measuring the rates of proton/electron transfer through time-resolved nanosecond and picosecond spectroscopy. It was found that the commonly made assumption of equilibrium in the excited state is hardly valid for many cases even when the protonation and deprotonation rates are relatively slow, e.g. carbazole[13]. Fast conformational relaxations following photo-excitation of labile molecules (such as benzil, naphthil, pyridil, mesitil) have also received the attention of the group[11].

(3) **Weak Molecular Interaction**

Following early work on molecular C-T complexes like hydrocarbon/azahydrocarbon—TCPA/I_2/quinone/TNB systems, they studied in detail multiple C-T bands and equilibrium between contact and solvent-separated ion-pairs in azine-methiodides. The radical pairs formed on photoexcitation were chosen for more recent studies. A small magnetic field of the order of 50 gauss competes with that produced by magnetic nuclei in influencing the rate of the ISC process in the solvent-separated radical pairs, and thus can influence the luminescence yield of exciplexes. With the help of an apparatus specially designed for studying small changes in luminescence, the environmental perturbation of the magnetic field effect on the exciplex luminescences from pyrene-dimethylaniline and cyanophenanthrene-anethole systems was explored. A direct role of the non-bonded protons in the spin-rephasing process has been offered as an explanation of the observations[15].

As a model for weak exciton interaction in molecular crystals, bi-molecules, where the two isolated chromophores weakly interact through space and through bond, have been chosen. The small splittings in these systems, resulting from weak exciton-type interaction, have been identified through high-resolution two-photon and one-photon spectroscopy[7].

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R D Desai

(1) Valency-Deflection Hypothesis

This hypothesis of C K Ingold and J F Thorrests on the *strained* or *uniplanar character* of the cyclohexane ring. Desai[1] showed that on the same hypothesis, the methyl and dimethylcyclo-hexane rings were strainless or multiplanar.

(2) Stereoisomerism of Cyclohexane-derivatives

An exhaustive study of the derivatives of methyl and dimethylcyclohexane showed that they were not the conformers derived from the boat and arm-chair forms of the multiplanar rings, but the *cis* and *trans* forms of the stable multiplanar chair form[2]. The evidence from NMR spectra was conclusive in this respect.

(3) Heterocyclic Compounds Containing Oxygen and Nitrogen as Hetero-Atoms

An exhaustive study of coumarins from cyclic β-ketonic esters and polyhydric phenols and their derivatives showed that these esters were more reactive than their open-chain analogues. Phosphorus oxychloride was more efficient as a condensing agent than conc. sulphuric acid. Thus, resacetophenone, 4-benzoylresorcinol, gallactophone, etc. underwent coumarin condensation in the presence of phosphorus oxychloride instead of conc. sulphuric acid. The Kostanecki acylation[3] of γ-orcacetophenone gave exclusively the chromones, while the isomeric β-orcacetophenone gave exclusively the coumarins. This observation facilitated the synthesis of some inaccessible 5-hydroxychromones. The cyclic β-ketonic esters reacted with aromatic amines at low temperatures, giving products which could be cyclized to tetrahydroacridones[4]. A new synthesis of naturally occurring 4-methylscopoletin, 4-methylfraxetin, and other partially methylated ethers of coumarins, was worked out. Polyphosphoric acid proved to be an elegant condensing agent for the synthesis of polyhydroxyxanthones[5] from polyhydric phenols and o-hydroxycarboxylic acids.

(4) β- and γ-Substitution in the Derivatives of Resorcinol

Resacetophenone, 4-benzoylresorcinol, etc. underwent Friedel-Crafts reaction with the simultaneous formation of β- and γ-substituted resorcinol derivatives. Orcinol, β-orcacetophenone, 7-hydroxy-4-methylcoumarin, etc. behaved similarly. This observation provided a very convenient method for preparing some rare *o*-hydroxyketones. This type of substitution also takes place when phenylisocyanate or isothiocyanate was condensed with the above compounds in the presence of anhydrous aluminium chloride[6], with the insertion of

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phenylcarbamido group (R F Leuckart Reaction). Malonic acid ester chloride, when condensed with resorcinol and its derivatives in the presence of anhydrous aluminium chloride, gives 4,7-dihydroxycoumarin derivatives.

(5) Studies in Naphthalene Series

The synthesis of a number of 2-acyl-, 4-acyl-1-naphthols and 1-acyl-, 6-acyl-2-naphthols was carried out to study their possible use as coupling components for azodyes. The comparative lability of the acyl groups in these monoacyl naphthols as well as of their diacyl derivatives was studied. They were reduced to the mono- and dialkyl derivatives, which showed antiseptic properties. Interesting chemical differences were observed between the derivatives containing long-chain alkyl groups and their lower homologues[7].

(6) Fries Reaction

A systematic study of the mono- and diacyl derivatives of di- and trihydric phenols, salicylic acid, 4-methyl-7-hydroxycoumarin was made to ascertain the mechanism of the reaction. The aryl esters of aromatic sulphonic acids also underwent this migration, giving a convenient method for the synthesis of hydroxysulphones[8].

(7) Studies in Tautomerism

The alkylation of a number of dihydroresorcinols showed that these cyclic β-diketones exhibited keto-enol tautomerism. Dialkylated dihydroresorcinols underwent alkaline hydrolysis giving γ-isobutyryl-butyric acids, which on Clemmensen reduction gave the corresponding long-chain fatty acids[9]. The tautomeric mobility of 2-aminobenzthiazole, 2-aminobenzoxazole and their hydroxy analogues was also established[10].

(8) Studies on Synthetic Dyes and Intermediates

Vat dyes from mono- and diaminophenanthraquinones were studied exhaustively to compare them with their analogues of anthraquinone in fastness, brightness and variety of shades, but these proved to be inferior to them in these respects[11]. The long-chain acyl derivatives of mono- and diaminoanthraquinones, though very bright yellow in colour, were not useful as vat dyes due to their unvattability. As they were soluble in fatty oils, they might be useful as oil pigments or disperse dyes for hydrophobic fibres like nylon or terylene. A number of phenylanthraquinonyl ureas and thioureas were found to be promising dyes as far as shades and their fastness to light and bleaching agents were concerned[12]. The arylamides of Schaffer's acid proved to be interesting as coupling components for dyes for cotton, wool and silk.

(9) Fluorescent Brightening Agents

The symmetrical derivatives of 4,4′-diaminostilbene-2,2′-disulphonic acid have proved to be important fluorescent brightening agents. Studies on various unsymmetrical derivatives of the same acid showed that some of them were equally or more efficient for paper, cotton and soap in this respect[13].

(10) New Types of Parachors

S Sugdon's parachor is based upon the fundamental properties of surface tension, density and molecular weight. Based on other fundamental properties like total heat of vaporization (λ), internal heat of vaporisation (λ_i), refractive index for the sodium line (n_D), and ultrasonic velocity of sound in liquids, parachors have been suggested and found to be equally interesting. Of all these, the Refrachor and Sonochor[14] are interesting owing to their constitutive effects.

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M L Dhar

The earliest research work of Dhar was on the mechanisms of organic reactions with particular reference to elimination reactions. This work, carried out in collaboration with Prof. E D Hughes and Prof. C K Ingold, was published in detail in 1948[1] and has become a standard reference in several books on physical organic chemistry [e.g. Ingold, *Structure and mechanism in organic chemistry* (G Bell Sons Ltd., London) 1953].

From 1950 until 1974, Dhar and his colleagues at the Central Drug Research Institute, Lucknow, carried out researches in two well-defined fields, namely (i) chemical and biological studies on medicinal plants of India, and (ii) chemotherapeutic studies in a variety of bacterial, protozoal and helminthic infections as also in the areas of hypoglycaemic and neuromuscular blocking agents.

Medicinal Plants

Detailed studies in the field of medicinal plants covered scores of plants and led to the isolation and structure elucidation of a variety of alkaloids, glycosides, terpenoids, etc.[2–7].

In mid-sixties, Dhar and his colleagues decided to carry out detailed screening of medicinal plants of India in general, for a wide spectrum of biological activities. This involved screening of standard plant extracts for antibacterial, antiprotozoal, antiviral, anticancer, hypoglycaemic and a wide range of pharmacological and other test systems. The concept was that a plant, collected carefully from a distinct ecological zone, may be examined in detail for its chemical constituents and biological activity only after the wide screen indicated justification for such detailed and expensive studies. Details of test systems adopted at the Central Drug Research Institute were first published in 1968[8]. This paper reported work on screening of the first batch of 285 plant materials comprising 237 species. Up to January 1973, 1173 plants drawn from 1120 species had been screened[9]. A fair number of medicinal plants were detected for their potentiality in a number of pathological conditions and many of these have been under detailed examination at the Central Drug Research Institute and other laboratories.

Chemotherapeutic Studies

Extensive studies were carried out on (i) synthesis of potential anti-mycobacterial agents, (ii) synthetic neuromuscular blocking agents, (iii) potential amoebicides, (iv) potential filaricides, (v) possible oral hypoglycaemic agents, and (vi) potential anticonvulsants. The basic philosophy governing this wide range of studies,

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covering a large variety of organic structural features, is explained briefly in the first paper of each series of papers published on the above-mentioned subjects between 1953 and 1970[10]. All these studies were based on providing as much logic as was possible in the design of molecular species which would enter into association or form linkages with possible bioreceptors that may be visualized to be involved in drug-receptor interactions in different pathogenic or metabolic disorders. This involved careful evaluation of the role such structural features of the designed molecules as the inter- and intramolecular electronic influences, molecular geometry, structural complementarity and spatial disposition of the interacting species, such as a probable drug and its possible, though only visualized, bioreceptor may indicate. An attempt was made throughout these studies at gaining a detailed understanding of all the various structural factors that could be involved in drug-receptor associations. Correlation of the data so obtained provided some logic for further design of possible new drug molecules.

Biological studies carried out by the biologist colleagues at the Institute provided a profound support. Many active compounds were spotted and followup studies revealed interesting chemical structures and some of these were under detailed biological studies from 1974 onwards.

The variety of organic reactions involved in this fairly large study involving the synthesis of different species, largely heterocyclic ring systems, provided occasionally interesting challenges which were suitably met.

All this work was published in over a hundred research papers largely in the *Journal of Scientific and Industiral Research* and the *Indian Journal of Chemistry.*

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M M Dhar

The research activities of Dhar have included studies on alkaloids, steroids, terpenoids, nucleic acids, peptides and antibiotics. The more important contributions are summarized below.

(1) Studies on Medicinal Plants

Convenorship of the medicinal plants project at the Central Drug Research Institute, Lucknow, during the period 1967-72, permitted remodelling of the project. In this programme, over 3000 plants have now been screened leading to the identification of specific biological activities in about 180 plants[1]. As a result, contributions in plant chemistry relate to the resolution of the structures of the proaporphine alkaloids isolated from *Croton sparsiflorus*[2], the bisbenzylisoquinoline bases from *Cocculus pendulus*[3], the naphthaquinones from *Arnebia nobilis*[4,5] and a new glycoside of *Ipomea leari*[6]. These studies demonstrate associations of new structures with biological activities. Some of these structures have since formed the basis of synthetic programmes aimed at obtaining drugs.

The significant biological activity of the *Croton sparsiflorus* alkaloids led to the determination of their absolute configurations[7] and also that of their precursor isococlaurine. The major naphthaquinone with promising anticancer activity from *Arnebia nobilis* is a potent inhibitor of reverse transcriptase.

(2) Nucleotide Studies

Along with two other research groups, a method involving the use of pyrimidine cyclonucleosides (anhydronucleosides) for the synthesis of internucleotide bonds was reported[8]. Bond formation by this method is achieved by selective attack of a nucleotide anion on the ribose carbon atom involved in the anhydro bond. The method is, therefore, specific and uses a minimum number of protective groups. These were extended to involve purine cyclonucleosides[9]. Dinucleoside phosphates have also been synthesized by the reaction of 5′-halogeno nucleoside with nucleotide anions.

(3) Peptide Studies

Studies in this field have been concerned with the synthesis of peptides that are of potential biological significance.

Steroidal polypeptides : Steroidal polypeptides had not been encountered in nature and had not been synthesized previously. An appreciation of their significance led to development of methods for their synthesis[10,11].

Synthetic substitute enzymes : The purpose of these studies was to synthesize peptides, which have the activity of natural enzymes and whose structure is based on available information about the active sites. Studies were aimed at synthesizing substitute ribonucleases and lysozymes.

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The approach to the ribonuclease problem was to synthesize a pentapeptide which had the amino acid residues expected to participate in enzymatic activity and which can take up a conformation, so that the amino acid residues are suitably disposed about an RNA chain[12]. Subsequently, the peptide chain was enlarged and modified.

The approach to the lysozyme problem was different. X-ray studies on hen egg-white lysozyme and an enzyme-inhibitor complex had led to the formulation of a mechanism for its (1,4)-β-glucoseaminidase activity. Bond breaking activity was ascribed to two carboxyl functions, one unionized and present in a hydrophobic region of the enzyme, and the other ionized and present in the outer hydrophilic region. Polymers were, therefore, synthesized having carboxyl functions in both hydrophobic and hydrophilic environments and demonstrated lysozyme-like activity[13]. A copolymer of L-phenylalanine and L-glutamic acid was found to have almost one-third the activity of the natural enzyme. As these copolymers have no binding sites, they are nonspecific glycosidases[14].

An extension of this concept was the synthesis of a decapeptide with suitably disposed carboxyl functions[14]. The design of such a peptide required anticipation of its conformation.

Cyclic tetrapeptides : The synthesis of cyclic tetrapeptides has been standardized. In accordance with expectations, some of these molecules are blastotoxic.

(4) Antibiotics Studies

Microbiological synthesis of antibiotic analogues : These studies are based on the hypothesis that antibiotics which have a peptide chain attached to a heterocyclic or other moiety owe their origin to detoxication of the heterocyclic or some other moiety by peptidation. If this hypothesis is correct, introduction of analogues of the heterocycle or the other moiety into the antibiotic-producing system should lead to the formation of antibiotic analogues. This hypothesis was tested with an echniomycin-producing culture. Echinomycin has a symmetrical structure containing two quinoxaline-2-carboxyl residues attached to a cyclic peptide. Introduction of quinazol-4-one-3-acetic acid into the culture medium was found to yield an analogue in which one quinoxaline-2-carboxyl residue had been replaced by a quinazol-4-one-3-acetyl residue.

These studies led to a hypothesis on the manner of formation of antibiotics. The suggestion that most antibiotics are from the group of secondary microbial metabolites formed by detoxication involving the attachment of a chemical entity to another moiety that is toxic to the culture[15] aroused interest, as this idea indicates a way for obtaining antibiotic analogues and for selecting the best antibiotic producing strains.

(5) Other Molecular Biology Studies

Immunogenic response : A mechanism has been proposed for the distinction of foreign proteins by living systems based on peptide dependent RNA synthesis[16]. With the use of a unique synthetic peptide, whose mRNA should be almost entirely purine, it was possible to provide experimental evidence that could support the hypothesis.

Interferons as tumour inhibitors : The first clinical trial employing an interferon inducer was used to treat 10 patients in K G Medical College, Lucknow[17]. Tumour development was arrested until immune response against the interferon inducer developed.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

N R Dhar

Dhar started research work on nitrite chemistry with Acharya P C Ray in the Calcutta University in 1911. In 1915, he went to England and did research work under Prof. J C Philip in the Physical Chemistry Department of the Imperial College of Science and Technology, London, for his DSc degree. He studied the mechanism of the reaction between mercuric chloride and oxalic acid induced by potassium permanganate at different temperatures. He discovered the photochemical reaction between oxalate and iodine and observed that in the dark this reaction is slow with a value of 7.2 for its temperature coefficient for 10°C rise in temperature. He also studied the kinetic reaction between oxalic acid and $KMnO_4$ and discovered that the reaction is unimolecular in the presence of a large quantity of oxalic acid. He further studied the kinetics of the oxidation of oxalic acid and chromic acid, quinine sulphate and chromic acid. In May 1917, he was awarded the DSc degree of the London University. He then went to France and joined the Sorbonne University, Paris under Prof. G Urbain in the Mineral Chemistry Department and worked on complex compounds. He prepared several cobalt and platinum complex amines and determined their electrical conductivity and electromotive force with the help of calomel electrode using metallic cobalt or platinum as electrode. In January 1919, he was awarded a State Doctorate of Science of France (Tres honourable), the highest recognition possible. In May 1919, Dhar was appointed to the Indian Education Service, and joined as Professor and Head of Inorganic and Physical Chemistry in Muir Central College, Allahabad on 19 July 1919. Shortly afterwards, the Muir College merged in the Allahabad University. For his classical researches in photochemistry, colloid chemistry, chemical kinetics, complex compounds, etc. he was acclaimed as the founder of physical chemistry in India. In 1934-35, he discovered photochemical nitrogen fixation in soil by slow oxidation of organic matter present in soil or added to it more in light than in dark. He further discovered that this nitrogen fixation is greatly increased on the addition of calcium phosphate or basic slag. For this discovery, Prof. Alaf Aslander of Sweden, Prof. Victor Kovda of U.S.S.R. and Lady Eve Balfour of UK proposed the name of Prof. N R Dhar to the Nobel Committee in Stockholm, Sweden for the award of a Nobel Prize.

Honorary DSc degrees were conferred on Dhar by Calcutta University, Viswa Bharati, Santiniketan Banaras Hindu University, Gorakhpur University and Allahabad University.

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Dhar has to his credit over 600 original papers and was the research guide for 150 DScs and PhDs from the Allahabad University. His research career spans over 75 years.

Dhar is the founder and Honorary Life Director of Sheila Dhar Institute of Soil Science, Allahabad University, established in 1935.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

K S G Doss

Doss, after a distinguished career at the Mysore University, worked in the Central College, Bangalore, from 1927 to 1943, as Research Scholar, Lecturer and Assistant Professor. During 1943-57, he worked at the National Sugar Institute, Kanpur as Physical Chemist and Professor of Sugar Chemistry and officiated as Director for one and a half years. During 1957 to 1967, he was the Director of the Central Electrochemical Research Institute, Karaikudi. He has made major contributions through his fundamental and applied researches, some of which are described below in brief.

(1) Fundamental Researches

Faradaic rectification[1] : Doss, along with his PhD student, H P Agarwal, was the first to discover the phenomenon of Faradaic rectification and to work out its theory. That the theoretical formulation is difficult can be seen from the fact that it had eluded formulation, with the result that a wrong formulation was given by the brilliant electrochemist Oldham. The phenomenon was pursued by a number of eminent electrochemists all over the world. It has led, at the hands of Barker and coworkers, to the development of a new powerful analytical technique, radio-frequency polarography, which can be used to estimate nanogram quantities of mixtures of metals in 0.01 ml solution. Further, the application of the phenomenon at the hands of Barker and Nurnberg had led to the development of the method for measuring the rates of even extremely fast electrode reactions (5000 cm/sec). Even after three decades of the discovery, there is no alternative method for such measurements. The discovery of Doss provided a new opening in the field of non-linear activity in electrode kinetics. This has led to a few new powerful techniques based on Faradaic distortion, Faradaic demodulation and Faradaic inter-modulation. Recently, there has been a practical application of the phenomenon in developing a probe for use by industry to make in-plant studies of instantaneous corrosion rates. A major advancement consisted in recognizing the dc contribution of second order terms in the electrode kinetics, which was invariably overlooked by previous workers.

Theory of contact angles[2] : At a very early stage in his career (1933), Doss developed a thermodynamic theory relating wetting and contact angles, modifying Young's equation. This has been confirmed and extended by a number of workers in India and abroad [Livingston H W, *J phys Chem* (1944); Sasaki, Kumanomido and Tsundoda, *Proc International Congress of Surface Activity*, Div IV A, 1958; Shenoi B A, Ramajayam S & Rangarajan N, *J electrochem Soc*

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Japan, **Z83** (1962) 300]. The original contribution consisted in examining the free energy changes on wetting, applying for the first time Langmuir's principle of independent surface action.

Activation in the formation of adsorption films at solution surfaces[3] : An important discovery of Doss was that many surfactant solutions formed adsorption films which could be studied by the balance. This finding led to a method of monitoring the rate of adsorption and to the establishment of the activation energy requirement as the cause of 'mysterious' slow variation of surface tension with time in a number of cases. It also led to the method of measuring cross-sections of surfactant molecules.

Theory of wedge effect[4] : Doss, along with K S Indira, was responsible for working out the theory of wedge effect, which has led to elucidation of the cause of explosions in chlor-alkali cells and the way to avoid the same.

Polarographic maximum of the third kind[5] : A new type of polarographic maximum was discovered by Doss along with V K Venkatesan while working with surfactants. This has been named by the well known electro-chemist Frumkin as the polarographic maximum of the third kind.

A new approach to explain electrochemical oscillations[6] : Doss, with K S Indira, has shown the importance of solid state effects in the behaviour of reversible electrode of the second kind and also in interpreting phenomena like passivation, pitting corrosion and electrochemical oscillations. These ideas are getting confirmed by recent investigations using sophisticated techniques.

A new method for finding zero charge potential[7] : Doss has worked out a new method for finding zero charge potential, which appears to be of great value in interpreting the Billiter-zero.

Photon, a soliton[11] : Doss's recent work has been on the nature of the photon. His contention is that the photon is the simplest soliton. He has been emphasizing the need for working out the physical picture of interference, diffraction, polarization and Rayleigh scattering in terms of photons instead of waves. He has calculated the size of the photons on the basis of depolarization measurements made by him.

Theory of relativity[12] : Doss has recently had a new look at the theory of relativity. He has indicated the possibility of explaining the observed relativistic phenomena in terms of the changes in effective dielectric and magnetic constants of vacuum with the relative velocity between the emitter and detector. He has critically assessed the possible prognosis of the concept.

His original approach involves consideration of the possibility of variation of ϵ and μ with the velocity of propagation of electromagnetic waves, relative to the detector.

Theory of interaction between surface active agents and acid base indicators : Doss attempted, for the first time, quantitative formulation of this theory on the basis of squeezing type of forces. Earlier workers had wrongly attributed it to Coulomb forces. This work has found application in developing new types of indicator papers for use in industrial process control.

Tensammetry : This technique, developed independently by Doss and Dr Breyer of Australia, has been referred to extensively (about 40 references) in the book by Breyer and Bauer on '*AC polarography and tensammetry*'.

(2) Applied Researches

Transient heater[8] : In the final stage of sugar manufacture, one gets a mixture of sugar crystals and mother liquor (molasses) which has to be cooled to get the maximum crystallization of sugar. Separation of molasses from the crystals by centrifugation poses a problem since the molasses is highly viscous (20,000-45,000 poises). It is necessary to reheat it by 10°-15°C. In the normal process of reheating in the crystallizers, a good amount of sugar redissolves and is lost in the molasses. Doss felt that this dissolution can be brought down by carrying out the heating without stirring. He calculated the dissolution that may occur under such conditions by applying the 'diffusion length' concept of Einstein and made the amazing observation that the dissolution may be as little as one-hundredth of the normal dissolution.

A test tube experiment gave a clue that it is practicable to heat the massecuites without stirring. The transient heater designed by Doss is now being used in about 25 factories, entailing a saving of about Rs 2 crores worth of sugar every yer. When all the factories adopt it, an annual saving of the order of about Rs 30 crores would result.

Resistence heating of massecuites[9] : This is an important contribution of Doss along with Vishnu in the applied field (Indian Patent 52753). Although the problem of reheating of massecuites was engaging the attention of technologists and engineers all over the world, it was Doss who analysed the problem and demonstrated that the best method to reheat massecuites was by resistance heating. This has been applied in practice in many countries—Australia, UK, Mauritius, etc. In India, about a dozen factories have adopted the technique recently, enabling saving of crores of rupees. This work has been superseded by Doss's new invention 'transient heater' discussed above.

A new process for the porous carbon electrodes[10] : From researches conducted along with Rao and Waheed, Doss developed porous carbon electrodes using an entirely new technique (Indian Patent 90957). These electrodes are now being used extensively in India.

Dry cells[13] : Doss's process for dry cells manufacture has been commercialized recently.

Mechanism of corrosion of iron cathodes[14] : Along with S R Rajagopalan and S Sampath, Doss investigated the cause of corrosion of end cathodes in the electrolysers in a fertiliser factory. This led to the establishment of a totally unexpected case of the phenomenon, viz. cathodic depassivation. This was causing loss of production of fertilizers to the extent of at least 10%. This phenomenon had earlier eluded solution by the experts of the suppliers (De Nora Co.), who have been in the field for decades.

New concept of drying bagasse to get process steam[15] : Doss, in his 78th year, has thought of a novel concept of drying bagasse to produce process steam, and is trying to work it out in collaboration with progressive sugar factories.

Selected Publications

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S Dutt

During his research career extending over a period of almost 45 years (1921-66), Dutt made substantial original contributions in the fields of organic chemistry, biochemistry, medicinal chemistry, industrial chemistry, and criminology.

Notable among the achievements in organic chemistry and related subjects are: (i) Preparation of synthetic dyestuffs from coaltar byproducts like phenanthrene, carbazole, thiodiphenylamine, etc.; (ii) preparation of fluoresceins and rhodamines from long-chain synthetic dibasic acids; (iii) preparation of synthetic fixed oils from newly synthesized fatty acids and glycerol; (iv) general methods for the preparation of (a) esters of α-unsaturated acids from malonic acid, and (b) esters of water-insoluble alcohols; (v) study of special organic reactions, such as (a) photoreaction in tropical subject, (b) putrefactive decomposition of Bengal silk cocoon, (c) jelly formation from Indian fruits and their pectin content; (vi) isolation of active principles (and in some cases synthesis too) of certain Indian medicinal plants, e.g. *Plumbago zeylanica, Plantago ovata, Calotropis procera* and *Glycosmis pentaphylla*; (vii) preparation of cellulose and paper pulp from non-traditional sources, e.g. wood of trees like banyan, peepal, haldu and tamarind, shrubs like sarcanda, ikira, hygrophyla reeds, etc. and herbal plants like safai grass, rosha grass, etc.; (viii) isolation and identification of constituents of essential oils and oleoresins from various Indian plants (or plant parts), e.g. *Pinus ibuja, Murrya kanogi, Cimum gratissimum, Cinnamomum camphora, Lantana camara, Mentha arvensis, Cannabis sativa*, jhingra, pan, Nagpur orange peel marjoranum, etc.; and (ix) isolation and physico-chemical examination of several non-conventional fixed oils like those of *Butea frondosa, Artemisia maritima, Dodonia viscosa, Salvia latica, Lacutea sceriola, Arbs precatorius, Vicia faba*, etc.

Among the industrial problems on which Dutt worked were the use of rectified spirit as motor fuel, and preparation of fuel oil from industrial wastes.

The topics on which Dutt made major contributions in the field of criminology include: (i) simulated forgery, traced forgery, disguised hand writing, (ii) identification of paper and ink and estimation of their approximate age as a means of detecting forgery of documents; (iii) examination of forged receipts bearing misdated, predated and postdated revenue stamps (for this, he made a collection of microphotographs of revenue stamps for the period 1934-64); and (iv) development of a system of classification of finger prints as a means of detecting forgery of finger

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prints; Dutt disproved the theory of Sir Edward Henry and Sir Ronald Ross that finger prints are sure methods of identification of criminals. He published a comprehensive 4-volume monograph on behalf of the Document Investigation Association of India, of which he was the President.

Dutt also did extensive work on criminology in relation to various types of weapons (cutting instruments, blunt instruments and fire-arms) used for committing crimes, including murder. He also published several papers on metallic and organic poisons, toxic gases, and bacterial poisons.

A notable discovery of Dutt was that of a stone from Rajasthan with extraordinary semiconducting properties, ideal for use in the preparation of transistors and radio receivers.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M V George

Current Research Interests

The current research interests of our group lie mainly in organic photoprocesses in solution, study of transient intermediates and electron transfer reactions.

Nanosecond laser flash photolysis studies of selected organic substrates have been undertaken to examine the role of transient intermediates, such as radicals, biradicals, singlet and triplet states, exciplexes and ion pairs in their phototransformations. Included in these studies are photo-induced electron transfer reactions[1], photochemical ring-opening reactions[2], photofragmentations and rearrangements[3], and phototransformations of several bichromophoric substrates containing 1,2-dibenzoylalkene moieties[4–8].

Electron transfer reactions through the interaction of potassium with several organic substrates are currently under investigation. Radical anions and dianions are formed in most of these reactions and they undergo further transformations to give a variety of products. In the presence of oxygen, for example, the radical anions give oxygenated products, which can be rationalized in terms of the involvement of superoxide, formed through electron transfer reactions. Cyclic voltammetric and pulse radiolysis studies are employed for the characterization of the radical anions generated from these substrates[9].

Past Research Contributions

The research efforts of our group during the past few years have been directed towards the study of organic reactions, in general, the broad areas of our interest being (i) organic phototransformations and photooxygenation reactions, (ii) organometallic chemistry and the chemistry of radical anions and dianions, (iii) acetylenic esters and ketones in the synthesis of heterocycles, and (iv) synthetic reactions and mechanistic investigations. The results of these studies have been summarized in several review articles[10–15], which list the original contributions.

Future Research Projections

The future research interests of our group will centre primarily around the study of phototransformations and transient intermediates. The basic objective of the work is to gain information on the outcome of steady-state photolysis and the role of transient intermediates in these reactions. Nanosecond laser flash photolysis studies will be carried out to understand the spectral and kinetic behaviours of the transients involved in the phototransformations of several classes of selected organic substrates. Also, attention will be paid to the study of several organic

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photoprocesses in organized media (zeolites, cyclodextrins, ~~silica,~~ titanium dioxide, etc.).

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

U R Ghatak

The main theme of the research work done by our group has been the development of methods for stereocontrolled organic synthesis, particularly in the fields of complex diterpenoids, diterpene alkaloids, and physiologically active natural products of contemporary interest. In this endeavour, the major emphasis has been directed towards gaining a deep understanding of conformational and steric factors of complex organic molecules which control bond formations in organic synthesis and has been focussed on new reactions that form such bonds in novel ways. Some of the more important contributions are highlighted below.

(1) Diterpenoids

In the early stage of the synthetic investigations in diterpenes, we developed a stereocontrolled total synthesis of (±)-podocarpic acid[1] and all the four possible diastereoisomeric 20-nor-deoxypodocarpic acid analogues[2]. In a comprehensive synthetic endeavour during the last decade, we have realized the construction of a few promising 'synthons' towards C_{19}- and C_{20}-gibberellins and related compounds by new and novel stereocontrolled methods[3-5]. Our most significant contribution in the field of complex diterpene alkaloids is the development of two new stereospecific synthetic methods[6,7] of general interest for the key tetracyclic bases[8], the established synthetic intermediates for *garrya* and *atisine* alkaloids. Very recently, we have reported[9] a biomimetic synthesis of the key intermediates towards stemodane and stemarin groups of complex diterpenes by a simple strategy, involving an intramolecular C-alkylation and regiospecific rearrangements.

(2) Bridged-Ring Systems

Terpenoids, alkaloids and many other complex natural products contain bridged-ring carbocyclic systems. In addition, bridged-ring compounds provide important intermediates towards stereospecific introduction of functional groups in cyclic systems as well as rigid models for conformational analysis, reaction mechanism, bond-strain, bond-angle distortion, proximity effects and spectral studies[10]. Many of these points have been reflected in our works relating to the bridged-bicyclo (3.2.1) octane and bicyclo (3.3.1) nonane carbocyclic systems[11]. The synthesis of (±)-des-N-morphinan, first reported by us, has been found to be a strong attractant for *Rhinoceros beetle*, a pest of coconut palm, in olfactometer tests[12].

(3) Intramolecular Alkylation by Cationic Cyclization Reactions and α-Keto-Carbenoids

During the synthesis of bridged-ring

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systems, some fascinating examples of intramolecular rearrangements and cyclizations through 1,5-hydride shift have been discovered[13] leading to a new cyclopentenone and cyclohexenone annulation method.

The acid-catalyzed intramolecular C-alkylation and alkylation rearrangements through unsaturated diazomethyl ketones, developed by us[14,15], provide a new and a versatile approach to the synthesis of complex carbocyclic systems related to a number of bio-active diterpenoids and polycyclopentanoids.

In addition to the synthetic efforts towards complex bio-active natural products, we have been deeply involved in the development of newer methodologies for carbon-carbon bond formation and cleavage reactions using transition metal catalysts.

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B N Ghosh

The equation connecting the streaming potential E and the electro-kinetic potential ζ of a capillary tube filled with a dilute solution of an electrolyte is well-known [Overbuk J Th G & Wijga P W O, *Rec trav chim*, **65** (1946) 556] and is written as follows:

$$E/P = v/i = (D\zeta/4\pi\eta S)/(R_{cal}/R_{exp}) \quad \ldots(1)$$

In Eq. (1), P is the pressure difference between the two ends of the uniform capillary tube of length L and cross-sectional area A; v, the volume of the solution; and i, the electric current passing through the tube per unit time; η, its viscosity; and S, its specific conductivity in bulk; D, its dielectric constant; and R_{exp} and R_{cal} represent the resistances determined experimentally and calculated using the equation $R_{cal} = L/AS$.

Rutgers and Bickermann have shown that the specific conductivity k_p of the solution inside the capillary tube is given by the expression:

$$k_p = S(1 + 2X/rS) \quad (1a)$$

where X represents the specific surface conductivity of the capillary wall; and r, the radius of the tube

$$\text{Hence,} \quad R_{exp}/R_{cal} = 1/(1 + 2X/rS) \quad (1b)$$

$$\text{and} \quad 2X = r(k_p - S) \quad (1c)$$

Combining Eqs. (1) and (1b), we get

$$\xi = \frac{4\pi\eta vS}{Di}(1 + 2X/rS)$$
$$= \xi_a(1 + 2X/rS) \quad \ldots(2)$$

$$\text{and } \xi = \frac{E}{P}\,\frac{4\pi\eta S}{D}(1 + 2X/rS)$$
$$= \xi_a(1 + 2X/rS) \quad \ldots(2a)$$

In Eqs. (2) and (2a)

$$\xi_a = \frac{4\pi\eta vS}{Di} = \frac{E}{P}\,\frac{4\pi\eta S}{D}$$

From Eqs. (2) and (1c), we get

$$\xi = \xi_a[1 + (k_p - S)/S] \quad \ldots(2b)$$

Eqs. (2) and (2a) and (2b) have been verified by Rutgers and Smet for hard glass capillary tubes [Rutgers A J & De Smet M, *Trans Faraday Soc*, **43** (1947) 102]. Using diaphragms made of fine glass particles of graded size, Wijga has found that Eq. (2) or (2b) does not yield the correct value of ζ.

Ghosh and his coworkers[1] have shown that under conditions in which the material of the particles forming the diaphram, their packing and S of the solution filling the diaphragm are maintained the same, Eqs. (2), (2a) and (2b) can be modified and expressed as

$$1/\zeta_a = 1/\zeta = m/r \quad \ldots(3)$$

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where m is a constant.

Using Eq. (3), they have succeeded in evaluating the true ζ of glass particles from Wijga's data and from the data of other authors[2] and true ζ of quartz particles from Bull and Gortner's data.

From streaming potential measurements of diaphragms made of soft glass particles of graded size, Schriever and Bleil have concluded that surface conductance correction leads to an improvement in the value of the potential but does not give its true value. Recently, Ghosh and his coworkers[3] have shown how from Schriever and Bleil's own data, the true streaming potential can be calculated by applying surface conductance correction alone.

Ghosh[4] has also evaluated the true ζ potential of the particles of an As_2S_3 sol coagulated at a given rate by different electrolytes using the following equation:

$$1/\xi_a = \frac{1}{\zeta} = m'/S \qquad \ldots (4)$$

where m' is a constant.

Many other lyophobic sols have been investigated by Ghosh and his coworkers and their results have led them to the conclusion that a given rate of coagulation of a colloid by different electrolytes is characterized by a definite value of the true ζ potential. Their results were published mostly in the *Journal of the Indian Chemical Society* between 1953 and 1964.

Colloidal Electrolytes

Such diverse substances as the natural and synthetic polyacids and their salts, dyes, micelles, soil colloids and other "association colloids" may be called colloidal electrolytes. Equations have been deduced by Ghosh[5,6] to account quantitatively for the variation with dilution in the hydrogen ion activity (H^+), specific conductivity (λ) and osmotic pressure (P) of (aqueous) sols of highly purified colloidal electrolytes. These equations may be written as follows:

$$(H^+) = \theta(H_S) + (1-\theta)H_i \qquad \ldots(5)$$

$$\lambda = \theta\lambda_s + (1-\theta)\lambda_i \qquad \ldots(6)$$

$$P = \theta P_S + (1-\theta)P_i \qquad \ldots(7)$$

In Eq. (5), H_S represents the hydrogen ion activity associated with a unit area of the diffuse electrical double layer of a particle or macromolecule in contact with the surface of the reversible electrode; θ, the fraction per unit area of the electrode surface with which the particles are in contact; and H_i, the hydrogen ion activity of the inter-micellar liquid. λ_s and λ_i in Eq. (6) and P_s and P_i in Eq. (7) have significance similar to that stated for H_s and H_i.

It may be pointed out that θ occurs in Eqs. (5), (6) and (7) because the ions present in the double layer of a particle or macromolecule must also be simultaneously present at the electrode surface, so that their activity can be recorded. It has been shown that $\theta = C/(C + K_0)$, where C is the concentration of the colloidal electrolyte expressed in an arbitrary unit and K_0 is a constant.

Eq. (5) can account satisfactorily for the variation with dilution in the H^+ ion activity of sols of palmitic acid, clay acids, gum arabic acids, etc. It has also been used to find the dissociation constant of polyacids like gum arabic acid, pectinic acid and polyacrylic acids of high degree of polymerization. Eq. (6) has been subjected to test using the data available in the literature on sols of cetyl sulphonic acid, congo-red, cetyl trimethyl ammonium bromide, benzopurpurin, etc. and has been found satisfactory.

Eq. (7) has also been subjected to test using literature data on sols of congo-red cetyl sulphonic acid, gum arabic acid, etc. and has been found satisfactory. The results of these investigations were published mainly in the *Journal of the Indian Chemical Society* between 1970 and 1980.

Electro-Viscous Effect

The Smoluchowski equation for the electroviscous effect may be written as follows:

$$\eta_{sp} = K\frac{CV}{100}\left| 1 + \frac{1}{\eta r^2 \lambda}\left(\frac{D\xi}{2\pi}\right)^2 \right. \quad \ldots (8)$$

where η_{sp} denotes specific viscosity, K is a constant; V, the specific volume of the colloid; and C, its concentration in grams per 100 ml of the sol; r, the radius of the particles; and the other terms have their usual significance.

Ghosh[7] has modified Eq. (8) by replacing λ by its value $\theta\lambda_s + (1-\theta)\lambda_i$, as given in Eq. (6) and then simplifying. The modified equation may be written as follows:

$$\eta_{sp}/C = K\frac{V}{100}\left[1 + \frac{A\xi^2(C+K_0)}{\lambda_s(C + K_0\lambda_i/\lambda_s)}\right], \quad (9)$$

$$\text{where } A = \frac{1}{2\eta r^2}\left(\frac{D}{2\pi}\right)^2$$

Eq. (9), with suitable alterations, depending on the experimental conditions, has been subjected to test using literature data on such sols as sodium thymus nucleate, gum arabic acid and its sodium salt, polyacrylic acids of different degrees of polymerization and on many other sols and has been found satisfactory. The results of these investigations were published in the *Journal of the Indian Chemical Society* between 1976 and 1981.

Strong Electrolytes

Ghosh[8,9] has pointed out that the expression for Kappa in the Debye-Huckel theory should be modified, since they did not take into consideration the activity coefficient of the ions in deducing it. The modified expression for Kappa, denoted by k_m, deduced by Ghosh may be written as follows:

$$k_m = [(4\pi e^2 \Sigma n_i Z_i^2 / DkT)\,(f_0/f)]^{1/2} \quad \ldots (10)$$

In Eq. (10), n_i represents the number of the ith ion per cc and Z_i, its valency; f_0 and f represent the mean activity coefficient of the ions outside and inside the "ion-atmosphere of the central ion", and the other terms have their usual significance.

After introducing some plausible assumptions and then simplifying, the following expression for k_m has been obtained[8,9]:

$$k_m = (s/\sqrt{a})[C^{1/3} - C_0^{1/3}] \quad \ldots (11)$$

where S consists of known constants; a represents the "effective ionic diameter" in Angstrom units; C, the concentration in moles per litre; and C_0 is a constant representing that value of C at which $k_m = 0$

Using this k_m, equations for the variation with concentration C of the mean activity coefficient f, the equivalent conductance λ, the viscosity η, the apparent molal volume

ϕ_v and the relative apparent molal heat content ϕ_L have been deduced[10]. The equations[9,11] for the mean activity coefficient and that for equivalent conductance are recorded below:

$$-\ln f = (S_f/\sqrt{a})[C^{1/3} - C_0^{1/3}] \qquad \ldots(12)$$

$$\lambda = \lambda_g - (S_\lambda/\sqrt{a})C^{1/3} \qquad \ldots(13)$$

In Eqs. (12) and (13), S_f and S_λ can be calculated from theory; *a* represents the "effective ionic diameter"; C_o has the same significance as stated already; and λ_g represents the equivalent conductance when C = 0. All the equations mentioned have been tested and found satisfactory.

J C Ghosh [*J chem Soc*, **113** (1918) 449, 790] was the first to propose that the equivalent conductance of a strong electrolyte varies as $C^{1/3}$ and his equation agrees with Eq. (13) mentioned above. The results mentioned above were published in the *Journal of the Indian Chemical Society* between 1980 and 1985.

Selected Publications

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2. Ghosh B N, Bandopadhaya S & Moulik S P, Evaluation of cell constant of porous pad made of fine particles and zeta potential of the particles by applying correction for surface conductance, *Proc natn Inst Sci India*, **A3** (1961) 193.
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R V Gopala Rao

Through the use of polynomial of ( )for representing pressure and using Maxwell's theorem of equal areas, an equation connecting vapour pressure of the liquid to the compressibility has been derived.

The phenomenological equation connecting compressibility to surface tension was found to reproduce satisfactorily the experimental results from the melting point to three quarters of the liquid range. This equation has been applied to non-metals and metals [Grosse A V, *Nature, Lond (Phys Sci)*, **232** (1971) 170; Grosse A V, *Germantown Laboratories—A report*, 1970 (work supported by U.S. Atomic Energy Commission under Contract AT (30-1)-4176. NYO—4176-4].

The pressure variation of bulk modulus has been connected to various liquid state properties. A dimensionless parameter 'δ' has been defined and used in the evaluation of molecular diameter.

The Rao-Rao equation has been used to explain the Carnevale-Litovitz constant [Azis R A, Bowman D H & Lim C C, *Can J Phys*, **50** (1972) 646].

Considerable work has been done on significant structure theory on a large number of molecules to obtain their thermodynamic properties.

The work on self-consistent approximation of low density expansion of $g(r)$ and with L-J (12, 6) potential has been shown to yield excellent results on fifth virial coefficients as quoted in a specialist periodic report [*Specialist Periodic Reports: Statistical Mechanics*, Vol. I; Senior Report K Singer (Chem Soc, London) 1973, 34].

The structure function of liquids (also called interference function), $S(K)$, has been investigated extensively under the mean spherical model approximation using chiefly the square-well potential as a perturbation over hard sphere potential for the study of a large number of liquid metals and some non-metallic liquids. This work has proved that one can predict the thermodynamic and transport properties of liquid metals with a square-well potential with a suitable choice of square-well potential parameters. An improved version of the MSM approximation was also evolved. In addition to square-well potential, other potential functions were also used to arrive at the structure function.

Methods of calculation of higher order correlation functions in the MSM approximation with a square-well potential as a perturbation over the hard spheres were also investigated.

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The potential parameters used in the evaluation of structure function have been used lucratively to predict transport properties of these liquids by various methods.

Also, the potential parameters have been used to calculate the partial structure functions in various alloys of these metals and hence their partial distribution function.

Through the use of perturbation theory, several equations of state with different potential functions have been formulated.

Earlier, an equation of state based on free volume theory was also formulated.

Work on molecular liquids has been done applying both orientation approach and the so-called reference interaction site model. The structure of several molecular liquids has been explained.

The quantum mechanical approach for studying the thermodynamic properties of various liquid metals has been adopted using the variation principle associated with Gibbs-Bogolieubov inequality.

A working hypothesis with sufficient proof has been put forward to evaluate the partial structures of fused salts and this method has been applied successfully to several fused salts.

A method has been evolved to evaluate the potential function from experimental structure function and has been applied successfully to several liquids and also to arrive at atom-atom potential function derivable from partial structures in molecular liquids.

The hard sphere solution of Percus-Yevick equation has been applied to explain the turbidity of sucrose solution with an empirical correction for the non-sphericity of the molecule.

The liquid state equations have been extended to calculate the elastic constants of solids. Both second order elastic constants and the third order constant C_{111} have been calculated from these extended equations. Further equations have been formulated to evaluate the pressure variation of elastic moduli and have been applied to a variety of solids. These results are found to be in satisfactory agreement with experimental results.

Along with Schofield's equations, the Rao-Dutta equation of state was used to explain the high frequency moduli of B_2O_3 and also its viscosity above the Arrhenius temperature; the diffusion constant was also evaluated.

Molecular acoustic equations have been formulated to evaluate the high frequency moduli (of both shear and bulk modulus) and also relaxation times.

Perturbation theories have been used to formulate simple equations of state in terms of packing fraction in liquids.

Earlier Work

The earlier work of Gopala Rao was connected with low temperature studies of solids under the inspiring guidance of Prof. W F Glauque NL. An apparatus similar to the one used by Gopala Rao at Berkeley was constructed at the National Chemical Laboratory, Pune to study second order transitions in solids, such as the transition of antiferromagnetic substances to paramagnetism, etc.

As facilities to go to temperatures below liquid nitrogen temperature were lacking, an adiabatic calorimeter to go to higher temperatures from room temperature was constructed.

A BET adsorption apparatus was constructed to study the surface areas of solids during their calcination.

Future Plans

A comprehensive study of liquids with applications to study thermodynamic, transport and acoustic properties of fused salts, globular proteins, alloys, ionic solutions and molecular liquids, etc. will be conducted using statistical and quantum mechanical methods.

Selected Publications

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18. Gopala Rao R V & Das Gupta B, Partial structure factors and diffusion coefficients of liquid K-Cs, *Phys Rev*, **32B** (1985) 6429.

Girjesh Govil

In 1970, we started a programme in molecular biophysics at the Tata Institute of Fundamental Research. The research programme interfaces with the then ongoing activities in the Chemical Physics and Molecular Biology Groups at the Institute. The main aims of this programme are to understand the structure, interaction and functions of biological molecules, dynamics and mechanisms of biochemical reactions and to utilize the knowledge thus gained to solve problems in bioengineering. The activities of this group with which I have had the privilege of being associated for the best part of my scientific career are reviewed here.

Facilities

In view of the multidisciplinary nature of the work involved and the complexity of the biological molecules, one had to create facilities comparable to the best in the world. Our earlier work centred around the use of the CDC computer available in the Institute[1-6]. Magnetic resonance was one of the strong points of the members who decided to get involved in this programme in the early phases. In 1983, the Department of Science and Technology decided to set up a 500 FT NMR National Facility at the Institute which has now become one of the most important assets for our studies. Computer software has been developed for various types of semiempirical and *ab-initio* quantum chemical calculations, for statistical calculations in drug design, and for computer aided molecular graphics. Other in-house facilities available to us include laser Raman spectroscopy, ESR and cyclic voltammetry.

Conformation of Biomolecules

Quantum chemical and Monte-Carlo calculations on the nucleotide backbone have led to the conclusion that non-bonded backbone interactions play a dominant role in determining the three-dimensional structure of nucleotides, polynucleotides and nucleic acids[4]. The helical structure acquired by each strand in a double helix corresponds to a conformation having minimum energy for isolated single strands. On the other hand, side chain interactions play a major role in stabilizing structures of polypeptides and proteins[1,2]. The NMR results on related molecules fully corroborate the theoretical predictions[7,8].

Drug Design and Drug-Membrane Interactions

The term 'drug design', introduced recently in chemical pharmacology, represents an effort to develop new drugs on a rational basis so as to decrease the trial-and-error factors and to predict the biological activity of the compounds prior

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to their synthesis[9]. This requires knowledge of precise biological and pharmacological events which occur in living systems following administration of the drug.

The interaction with biological membrane plays an important role. Magnetic resonance techniques (NMR and ESR) have been used in our laboratories to study the interaction of drugs with biological membranes and to study their effects on membrane properties, such as its molecular organization, fluidity, permeability, etc.[10,11]. The binding profiles of a number of membrane active drugs have been studied. These studies have been correlated with the functional aspects of drug molecules.

Recognition Schemes for Protein-Nucleic Acid Interaction

Specific protein-nucleic acid interactions play a key role in several stages of information regulation and transfer. However, unlike the Watson-Crick base pairing for nucleic-nucleic acid interaction, the rules for protein-nucleic acid interactions are yet to be understood clearly.

The molecular forces involved in protein-nucleic acid interaction are electrostatic, stacking and hydrogen-bonding. These interactions have a certain amount of specificity due to their directional nature and the spatial contributions of the steric effects of different substituent groups. Quantum chemical calculations[12,13] on these interactions have clearly brought out such features.

While the bonding energies for electrostatic interactions are an order of magnitude higher, the differences in binding energies for structures stabilized by hydrogen-bonding and stacking are relatively small. Thus, the molecular interactions alone cannot explain the highly specific nature of binding observed in certain segments of proteins and nucleic acids. It is, therefore, logical to assume that the sequence dependent three-dimensional structure of these molecules helps to place the functional groups in the correct geometry for a favourable interaction between the two molecules.

We have recently carried out 2D-FT NMR studies[14] on the oligonucleotide GGATCCGGATCC. This oligonucleotide sequence has two binding sites for the restriction enzyme Bam HI. The conformation of this molecule is predominantly B-DNA, except near the binding sites, where the ribose ring prefers a 3-*endo* conformation. This interesting finding raises the general question about the presence of specificity in the inherent backbone structures of proteins and nucleic acids as opposed to specific intermolecular interactions, which may induce conformational changes to facilitate such binding.

Biochemical Fuel Cells

A biochemical fuel cell is a device which converts chemical energy into electrical power. The catalysts used in this process can be either inorganic or organic type, giving rise to 'inorganic fuel cells' or 'biochemical fuel cells', respectively. Biochemical fuel cells use either micro-organisms or enzymes as active components to carry out electrochemical reactions. The efficiency of such a device can be theoretically as high as 90%. The difficulty in attaining these values arises due to sluggishness of electron transfer from the active site to the conducting electrode. This can be overcome by using mediators or by immobilizing active components on electrodes. We have immobilized FAD-glucose oxidase on a graphite electrode using a semiconducting chain as a bridge. At the present stage of development, such a device lacks high current densities, which is essential for commercial power generation, but it can be used in applications such as pacemakers and glucose sensors[15].

NMR Studies on Intact Cells

The availability of the 202 MHz ^{31}P NMR facilities has made it possible to conduct studies on live bacterial cells. Studies on the metabolism of cells under different physiological conditions have been initiated.

A multidisciplinary programme like the one described here can succeed only through team-work. A major reason for the success of our programme is the mutually complementary background of the team-members: solid state physics, physical and organic chemistry, chemical engineering, pharmacology and biochemistry. I am extremely fortunate to have among my collaborators several young dynamic graduate students. While some of these names appear in references, I would like to take this opportunity to thank all my colleagues who have contributed to this programme.

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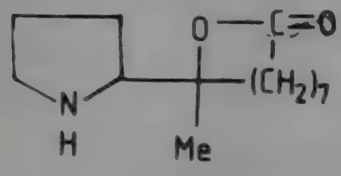
T R Govindachari

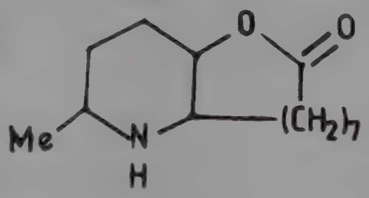
The richness of Indian flora (over 20,000 species) and the medicinal value of many of them have contributed to the fact that the chemical investigation of plants has been a major area of interest of organic chemist in India. The work of Govindachari and his associates, first at the Presidency College, Madras, and later at CIBA-GEIGY Research Centre over a period of 35 years, has led to the isolation of new novel types of compounds mainly in the fields of alkaloids, terpenoids and oxygen heterocycles, which were often the first in a particular class. Portions of this work have been reviewed[1]. Some of the more important contributions in structure elucidation of these plant products are reviewed here in roughly chronological order.

(1) Structure of Carpaine and Pseudocarpaine

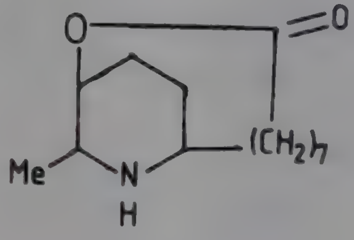
The alkaloid carpaine isolated from



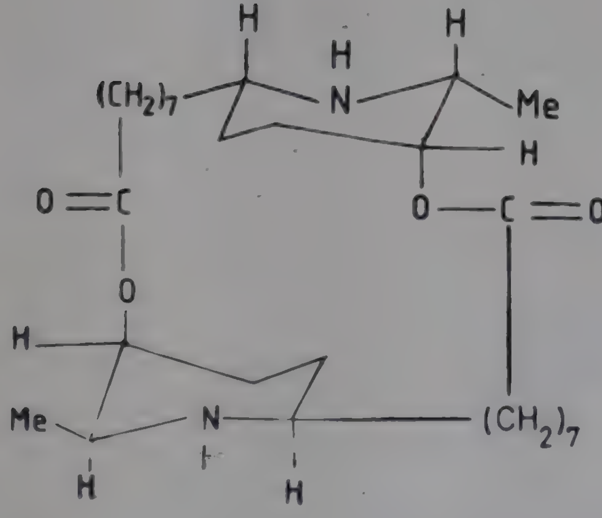
(1)



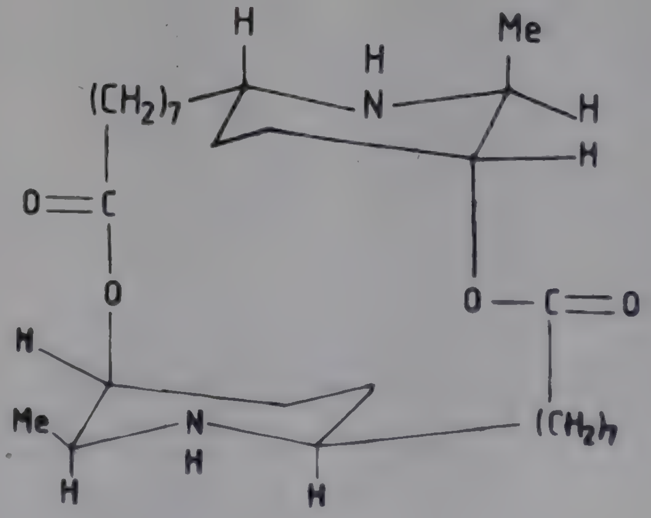
(2)



(3)



Carpaine (4)



Pseudocarpain (5)

Director, R&D, Amrutanjan Ltd., Madras-600022; *Residence* : 22, Crescent Park Street, T. Nagar, Madras-600017.

Carica papaya L. was incorrectly assigned structure **1** and later shown by its relation to ethyl carpyrinate (**2**) to have structure **3**[2,3].

Much later, with the advances in mass spectrometry, carpaine was shown to have the dimeric structure **4** by Spiteller and Spiteller [*Mh Chem*, **95** (1964) 1234].

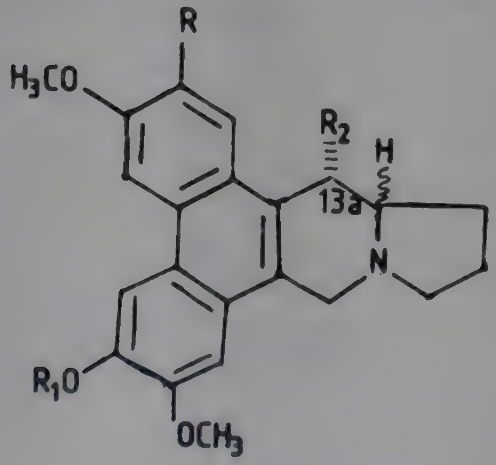
Pseudocarpaine, a minor alkaloid of the plant, was considered to be epimeric with carpaine at C-3. However, reinvestigation of its mass spectrum (M^+ at m/e 478) showed that pseudocarpaine also is a dimer. Chemical experiments and NMR analysis of the 100 MHz spectra of carpaine and pseudocarpaine led to the relative stereochemistry shown by structures **4** and **5** for these compounds[4].

(2) Alkaloids of *Tylophora asthmatica*

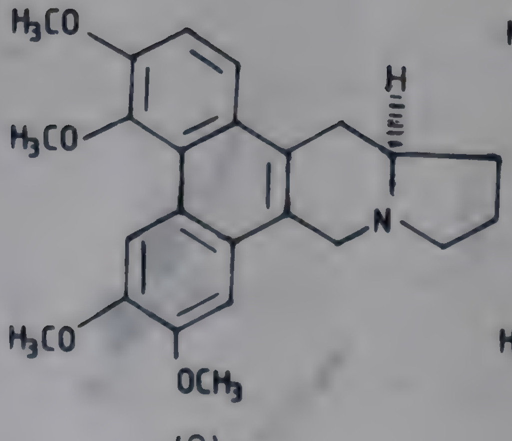
The leaves of *Tylophora asthmatica* Wright *et* Arn are used in folk medicine as a cure for asthma. In an effort to isolate the active principle, several alkaloids, the first members of a group of compounds having the novel phenenthroindolizidine ring system, were isolated—tylophorine (**6**), tylophorinine (**7**), tylophorinidine (**8**), *d*-isotylocrebrine (**9**) and the seco-alkaloid, septicine (**10**), as well as quaternary alkaloids. All aspects of the structure and stereochemistry of these alkaloids have been established and the work has been reviewed[5].

(3) Wedelolactone

Wedelolactone (**11**), the first



(6), R = OCH_3; β-H at 13 a
$R_1 = CH_3$; $R_2 = OH$
(7), R = H ; α-H at 13 a
$R_1 = CH_3$; $R_2 = OH$
(8), R = H ; β-H at 13 a
$R_1 = H$; $R_2 = OH$



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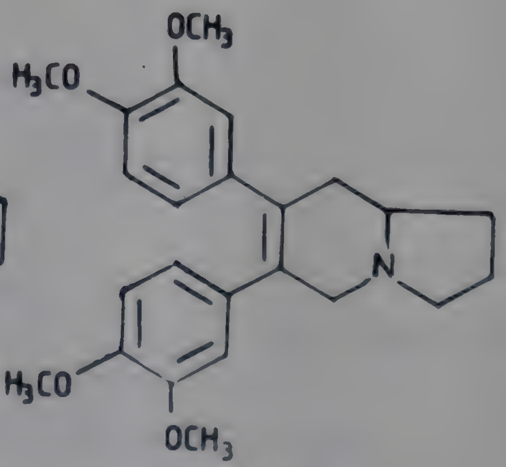
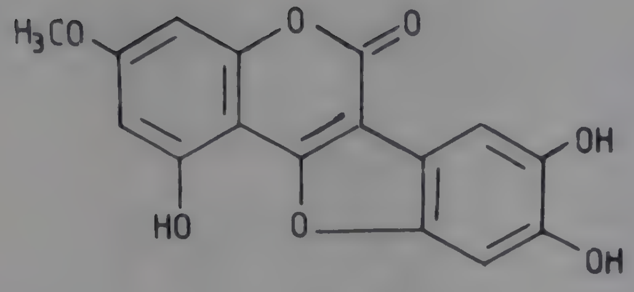
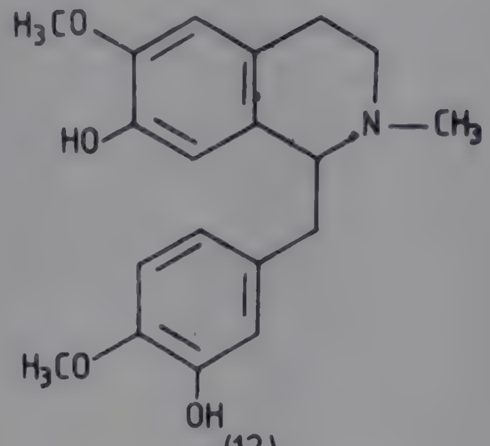


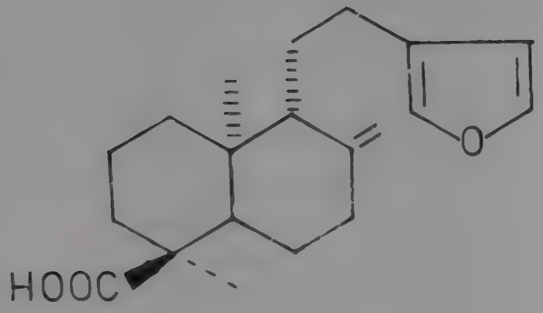
(10)


H3CO
O
O
OH
HO
O
OH

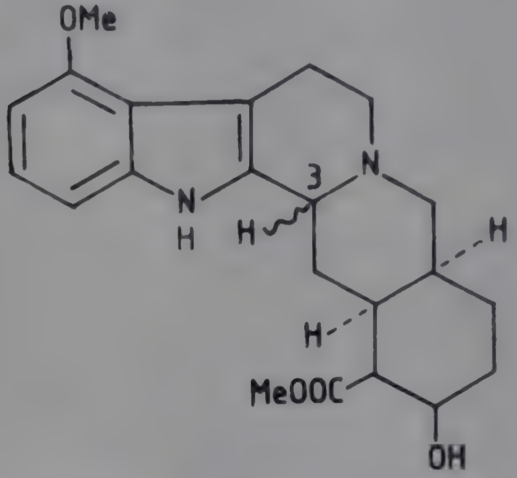
(11)


H3CO
HO
N—CH3
H3CO
OH

(12)

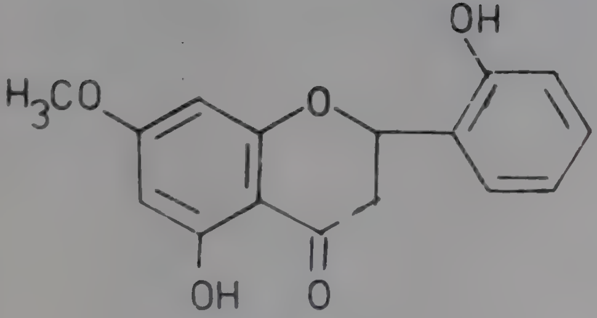


(13)

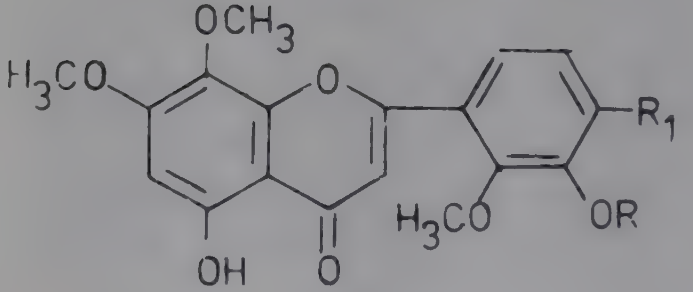

OMe
N
H
3
N
H
H
H
MeOOC
OH

(14), C_3-β-H Venenatine

(15), C_3-α-H Isovenenatine


OH
H3CO
O
OH
O

(16)
Echioidinin


OCH3
H3CO
O
R1
H3CO
OR
OH
O

(17), R = R_1 = H Wightin
(18), R = CH_3; R_1 = OCH_3 Serphylline

representative of the class of coumaranocoumarins, was isolated from the medicinal plant *Wedelia calendulaceae* Less. reputed in Ayurveda for the treatment of jaundice. The structure was proved by degradation and synthesis on classical lines[6-8].

(4) Reticuline

From the root bark of *Anona reticulata* Linn., the diphenolic benzylisoquinoline alkaloid reticuline was isolated and its structure established as **12**, which was later confirmed by synthesis[9,10]. Reticuline is an important biogenetic precursor of a number of alkaloids with different skeletal systems, e.g. protoberberine, benzophenanthridine, aporphine and morphine. With the isolation and structure elucidation of reticuline, the biogenetic pathway of a number of these alkaloids could be established.

(5) Polyalthic Acid

Polyalthic acid was isolated from *Polyalthia fragrans* (Anonaceae) and shown to have structure **13** through degradation studies[11].

(6) Venenatine

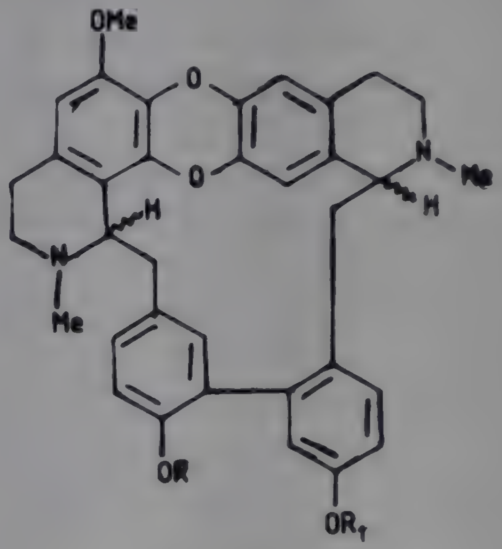
From the bark of *Alstonia venenata* R.Br., two new indole alkaloids, venenatine (**14**) and isovenenatine (**15**) (echitovenine), were isolated and assigned structure based on degradation studies[12].

(7) Andrographis Flavones

From plants belonging to Andrographis species, a group of flavones with unusual oxygenation pattern were isolated. Echiodinin (**16**) from *A. echioides*[13], wightin (**17**) from *A. wightiana*[14] and serphylline (**18**) from *A. serphyllifolia*[15] have a 2′-, 2′, 3′- and 2′, 3′, 4′-oxygenation pattern in the B-ring.

(8) Alkaloids of *Tiliacora racemosa*

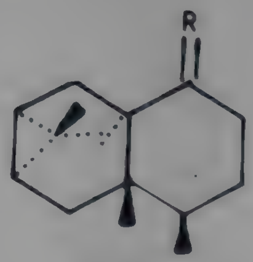
From *Tiliacora racemosa* Colebr. (Menispermaceae), a number of bisbenzylisoquinoline alkaloids were isolated, which are unique in having the isoquinoline moieties joined through a diphenyl unit and not through a diphenyl ether unit, as is common. The essential features of the structures of tiliacorine **19** and the accompanying alkaloids were established by degradation and synthesis[16,17]



(19), R=Me,R$_1$=H
or vice versa
Tiliacorine
Tiliacorinine

(9) Ishwarone

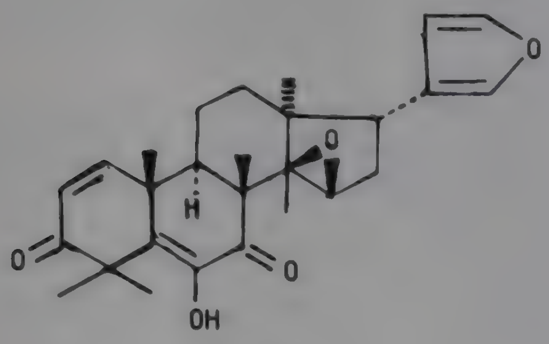
The structures of ishwarone (**20**), first isolated in 1935 from *Aristolochia indica* (Aristolochiaceae) and ishwarane (**21**), which are rare tetracyclic sesquiterpenes with a novel skeleton, was elucidated in 1970 by extensive chemical degradaion[18,19].



(20),R=O Ishwarone
(21),R=CH$_3$ Ishwarane

(10) Cedrelone

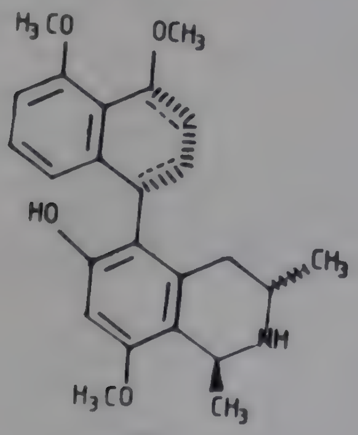
Chemical and spectral investigations, combined with biogenetic arguments, led to structure **22** for cedrelone[20], the bitter principle of *Cedrela toona*.



(22)

(11) Alkaloids of *Ancistrocladus heyneanus*

A novel group of alkaloids has been isolated from *Ancistrocladus heyneanus*, the only species in India of the genus *Ancistrocladaceae*. The major alkaloid, ancistrocladine, has been assigned the structure and stereochemistry depicted in **23**. These alkaloids are unique in being the only isoquinoline alkaloids arising from acetate units instead of the usual aromatic amino acids. The chemistry of this group has been reviewed[21].



(23)

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Jagdish Shankar

From the very start of his research career, Shankar organized work in various chemical and metallurgical aspects and helped in the formulation of plans of research in these areas for development of nuclear energy in the contry. He organized laboratories and created facilities in diverse fields, such as analytical, inorganic and physical chemistry, chemical engineering, metallurgy, spectroscopy, etc. in temporary laboratories he built in two large dilapidated halls of what used to be a textile mill in the city, and later in Trombay. From the Chemistry Division as it existed in the 50's, a number of sister divisions and sections were evolved in the course of time. Although situated in rather drab surroundings until 1966, he was able to create some of the most modern and sophisticated facilities for analysis, including spectrochemical and mass spectrometric analysis and other areas of physico-chemical research, which were rated at the time as the best in the country. It was in these laboratories that a large band of highly qualified and motivated young chemists were produced, who are now leading different disciplines in chemical work at the Bhabha Atomic Research Centre (BARC).

His interests in chemical research cover a wide field and include, among other specialized areas, recoil chemistry, radiation and photochemistry, X-rays and crystal structure and a wide spectrum of research in metal complexes.

In the very early years, he organized programmes and contributed to the evolution of physical and chemical procedures for upgrading low grade uranium ores, which are generally found in the country. He evolved a method for successful leaching of uranium and its recovery using ion exchange resins, which remains the first published account of such a technique in literature. This laid the foundation for the utilization in the atomic energy programme of the vast resources of low grade uranium found in India.

In the field of recoil chemistry, he studied the consequences of recoiling atoms subsequent to nuclear reaction in a compound in the solid state. In this subject, he established and nurtured research which attracted worlwide attention and his group has often been referred to as the 'Trombay School'. It was because of his work in recoil chemistry that he was able to determine the cause of fouling of the fuel elements in the large research reactor now known as CIRUS soon after it became critical in 1960 and to effectively clean up the deposits, so that the fuel elements could be used over again for their full life.

In the field of radiation chemistry, he carried out researches and organized a

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Formerly, Head, Department of Chemistry, Bhabha Atomic Research Centre, Trombay, Bombay-400085; *Residence* : 4, Saras Bagh, Deonar, Bombay-400088.

large group studying reactions of hydrated electrons, radiation-induced polymerization and photochemistry. These contributions have led to a large number of publications in basic and applied chemistry. During this work, he showed that an electron may sometimes pair with an H_2O^+ before hydration.

Recognizing the importance of ultra-high purity materials long before these became the mainstay of a number of sophisticated industries, he initiated programmes on the chemistry and metallurgy of ultra-pure non-ferrous metals. A spin-off of this activity was the establishment under his supervision of the Special Materials Plant at Hyderabad, where over a dozen metals of very high purity are made on a fairly large scale.

In reactor chemistry, he focussed attention from the very early days of operation of our reactors on the importance of coolant/clad interactions and the chemistry of coolant and moderator systems, and the corrosion chemistry of reactor materials in high radiation environments. It was at his initiative that a new section was started in the early seventies, now called the Water and Steam Chemistry Division, where interaction of very high temperature and very high pressure water is studied.

Shankar has always encouraged indigenous instrumentation. Even for his own PhD, he built an X-ray generating set and Debye-Sherrer X-ray tube. Under his guidance, know-how was developed in the field of precision gas chromatographic instrumentation. He was responsible for getting indigenously fabricated equipment for mineral dressing, ore extraction and radiochemical work. In 1972, he created interest in BARC in the fabrication of an artificial kidney, only 20×8×8 cm in size with pressure drop across it so small that it would not require an external pump for the blood to flow through it, the heart of the patient itself acting as the pump. This has now been developed and tested fully and is ready for commercial manufacture.

Shankar had many other interests. He organized the Library and Information Services of BARC, which today occupy a unique position in the country. He had taken keen interest in the training of personnel required in the DAE. He was very closely associated with the Training School at BARC and was in charge of it for many years after its inception in 1957.

Scores of students have taken their doctorate under his guidance and they are now located in positions of leadership in BARC.

He has been a member of the editorial boards of several national and international journals. He was President of the Chemistry Section of the Indian Science Congress (1965) and President of the Indian Chemical Society (1971-72). He is a Fellow of the Indian National Science Academy (1969) and the Indian Academy of Science (1975).

During the last few years, he has tried to develop research in liquid crystals and in the chemistry of certain naturally occurring medicinal plants.

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A C Jain

Natural products have served mankind since antiquity as articles of not only food, clothing and shelter but also of drugs, dyes, perfumes, insecticides, etc. They have guided chemists to make them available synthetically and to design other synthetic compounds better than themselves and helped in the taxonomy of plants and fungi. They have further revealed new reactions. Among natural products, polyphenols, quinones, steroids, terpenoids and porphyrins constitute large and important groups of compounds. More than 200 research papers during the last 35 years have been published by us in these groups of compounds. This research work is discussed below under four major heads.

(1) New General Synthetic Methods in Polyphenols

Porphyrins, which play an important biological role in the form of haemoglobin and chlorophyll, were synthesized by a new method, using pyrromethanes and pyrromethenes[1].

Since chalcones are the recognized precursors of naturally occurring isoflavones and 3-aryl 4-hydroxycoumarins, new general methods for their synthesis were developed. 2′-Benzyloxychalcone epoxides were rearranged in the presence of BF_3-etherate and subsequently cyclized to afford a general synthesis of isoflavones[2]. Similarly, 2′-hydroxy-α-methoxychalcones were oxidized with alkaline hydrogen peroxide and then rearranged to 3-aryl-4-hydroxycoumarins[3]. Using these general methods, a number of naturally occurring compounds have been synthesized not only by us but by others also.

2-Methylisoflavones have been synthesized from 2′-hydroxyl-α-methylchalcones using thallium nitrate in methanol for rearrangement[4]. This constitutes a biomimetic synthesis of these natural compounds.

Very recently, an elegant and highly useful synthesis of hydroxyisoflavanones, which are important phytoalexinals and also used in the synthesis of pterocarpanoids and rotenoids, has been developed[5]. It consists in mild protection of hydroxy groups of desoxybenzoins, α-hydroxymethylation, cyclization and deprotection.

A synthesis has been developed for another group of homoisoflavanones[6] using 2′-hydroxydihydrochalcones, which have been established as their biological precursors.

A new method of glycosidation of phenols was developed using orthoesters[7]; this method has been used quite frequently.

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Catechins have been synthesized recently from C-cinnamylated phenols by the steps of epoxidation and controlled cyclization[8].

(2) Biogenetic Type of Synthesis of Natural Polyphenols and Related Compounds

The total synthesis of many natural compounds has been accomplished. The strategy of these syntheses was mainly to adopt a biosynthetic pathway using laboratory reagents. Some important syntheses are as follows.

Isopentenylated polyphenols became important after 1964 because of antijuvenile hormonal activity of some and tranquilizing effect of others (cannabinoids). Hence, considerable activity has gone into their synthesis. Two methods of nuclear prenylation (using prenyl bromide in the presence of methanolic alkali and 2-hydroxy-3-methyl-2-butene in the presence of a Lewis acid) and two methods of pyrenylation (DDQ oxidation of *ortho*-prenyl phenols and thermal rearrangement of 1,1-dimethyl allyl ethers) have been used in the synthesis of natural polyphenols. Among many such examples in different groups of chalcones, flavanones, flavones, flavonols, 2-methylchromones, isoflavones, 3-aryl-4-hydroxycoumarins, 3-methyl-4-hydroxycoumarins, and xanthones, the following important examples could be mentioned: osajaxanthone[9], robustic acid[10], robustin[11], pomiflerin[12], auriculasin[12], alpinum isoflavone[13], osajin[13], sericetin[14], carpachromene[15], lupinifolin[16], bavachalcone[17], luteone[18] and parvisoflavones[18].

Among other total syntheses of natural products, those of tlatlancuayin[19], preremirol[20], acronylin[20], evodionol[20], rhamnetin[21], melisimplin[22], oxyayanin B[23], ougenin[24] and distemonanthin[25] could be cited; these use selective protection methods.

Perhaps the most elegant synthesis is of licoflavone A[26], which makes use of O-prenyl as the protecting group and its deprotection under alkali; the other methods failed. Similarly, the synthesis of erythrinin A[27] was accomplished in a remarkable manner using thallium nitrate for the oxidation of dihydropyranochalcone and DDQ oxidation.

(3) Study of Some Important Reactions and Rearrangements

A large number of secondary reactions have been recognized in the biosynthesis of polyphenols. Among the well-known ones are aromatic methylation, prenylation, cinnamylation, hydroxylation, dehydroxylation, etc; the more recent ones are aromatic armethylation and diarmethylation. Laboratory reactions simulating these have been carried out. The work on C-methylation[28,29] was reviewed[28], as also that on nuclear hydroxylation[29] and dehydroxylation[29]. The work on C-prenylation is briefly mentioned above. Nuclear cinnamylation in isoflavones[30], chromones[30] and other polyphenols has been accomplished using cinnamyl alcohol/cinnamyl bromide.

Recently, aromatic benzylation[31] and aromatic benzhydrylation[32] have been carried out, and synthesis of uvaretin, isouvaretin, etc. achieved.

Claisen rearrangement is an important sigmatropic rearrangement which has now been used extensively to rearrange prenyl[33] and cinnamyl[34] ethers. This gives a variety of cyclic and acyclic compounds whose constitutions have been established on the basis of extensive NMR data.

The Michael addition of dipyrromethenes[35] and 2′-hydroxychalcones[36] has afforded cyclic products; those from the former illustrated similar biosynthesis of chlorophyll and those from the latter gave kinetically controlled new 4H-pyran derivatives and cyclohexenone derivatives which have been converted into biologically active indazole derivatives[37].

Base-catalyzed rearrangement of angularly condensed 2,2-dimethyl-2H-pyrano derivatives in chromones, flavones and isoflavones has been used to provide difficultly accessible linearly condensed isomers[38]. Similar base-catalysed rearrangement of 3-benzylidene-4-chromanones has afforded 3-benzylchromones and 3-methylflavones[39]; both these groups are naturally occurring.

Reaction of 2′-hydroxychalcones with methylene iodide has produced a new class of compounds—benzoxepinones[40].

(4) Isolation and Constitution of Natural Products

Chemical examination of the plant *Putranjiva roxburghii*[41] and wood-rotting fungi, viz. *Ganoderma australe*[42] and *Fomes fastuosus*[43], has afforded many new triterpenes—putrolic acid, putranjivic acid, putrone, putrol, lanosta-8,25-dien-3-ol, etc. Their structures have been established on the basis of spectral data, including ^{1}H-NMR and MS.

Isolation of plant phenolics from *Pterocarpus indicus* heartwood, *Psoralia corylifolia* seeds[42] and *Sophora indica* roots has afforded several new compounds.

Isolation of plumbagin from *Arnebia hispidissima*[43] roots as early as 1965 is highly significant because of the recent finding that it is a safe antifertility agent.

(5) Future Lines of Work

Besides the above lines of investigation, work on enzyme models is proposed to be pursued. It involves designing of suitable and simple molecules which could simulate the action of enzymes and coenzymes.

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B S Joshi

The most significant work of Joshi during the last two decades has been the isolation of a variety of natural products from plants and application of modern physical methods in structure elucidation of these compounds. He has carried out a systematic examination of many Indian medicinal plants, especially from the Western Ghats of India[1]. He has also examined these plants for their biological activity and worked on the isolation of the active constituents. His objective was to evaluate scientifically the claims of indigenous remedies of many medicinal plants and Ayurvedic preparations. In this connection, clinical trials were carried out on Ayurvedic drugs in the areas of diabetes and hepatitis.

Joshi's research work in the chemistry of natural products has led to the discovery of several novel compounds belonging to the classes of alkaloids, sesquiterpenoids, diterpenoids, triterpenoids, flavonoids, coumarins, lignans and quinones.

(1) Alkaloids

The structure of mitragynine, the major alkaloid of *Mitragyna speciosa* Korth, was reinvestigated and it was shown to be 9-methoxycorynantheidine and not the one proposed earlier by Hendrickson. Villalstonine, isolated from *Alstonia macrophylla* Wall., was shown to be a dimeric indole alkaloid, based on degradative and mass spectral studies[2]. An antibiotic, pimprinine, isolated from *Streptomyces pimprina*, was shown by degradation and synthesis to be 5,3′-indolyl-2-methyl oxazole. Heyneanine, an alkaloid of the iboga type, was isolated from *Tabernaemontana heyneana* Wall. and its structure derived by ^{1}H-NMR, mass spectra and correlation studies[3]. The structure for the oxindole alkaloid tabernoxidine, isolated from the same plant, has been proposed. Novel carbazole alkaloids were isolated from plants belonging to the family Rutaceae[4]. Heptaphylline, 6-methoxyheptaphylline and indizoline were isolated from the genus *Clausena*. From *Murraya koenigii* Spreng. (var: Katnim), the carbazole alkaloids mahanimbine, isomahanimbine, girinimbine and koenimbidine were isolated and their structures established[5]. Correct structure was derived for piplartine, an alkaloid from the roots of *Piper longum* Linn. Four novel alkaloids, piperstachine, cyclostachine A, cyclostachine B and cyclopiperstachine, were isolated from *Piper trichostachyon* C. DC. and their structures derived on the basis of ^{1}H-NMR and ^{13}C-NMR spectra. Their structures were confirmed by syntheses[6]. From the bark and roots of *Ailanthus malabarica* DC., eight β-carboline alkaloids were isolated and their structures elucidated by spectral methods. The structures of tatsiensine, tatsnine and

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deltatsine, three novel C_{19}-diterpenoid alkaloids isolated from *Delphinium tatsienense* Franch., were solved mainly through ^{13}C-NMR studies[7]. From *Aconitum columbianum* Nutt. and *A. forrestii* Stapf., a number of new C_{19}-diterpenoid alkaloids have been isolated and their structures determined.

(2) Sesquiterpenes[8]

The structure of parthenolide isolated from *Michelia champaca* was deduced by degradation and spectral studies and the earlier formulation of Sorm *et al.* was shown to be incorrect. From the roots of *Neolitsea zeylanica* Merr., a number of furano germacranolides, viz. neolinderane, linderane, zeylanine, zeylanicine and zeylanidine, were isolated and their structures elucidated. *Neolitsea fischeri* Gamble gave fischeric acid and isofischeric acid. The structure of enhydrin isolated from *Enhydra fluctuans* was revised and confirmed by determining the X-ray crystal structure of enhydrin bromohydrin. Clausantalene, isolated from *Clausena indica* Oliv., was shown to be a β-santalane type of sesquiterpene. The mass spectral fragmentation of germacranolides has been studied.

(3) Diterpenes and Triterpenes

Veprisone, a limonoid isolated from *Vepris bilocularis* Engler, was shown to be methyl *epi*-iso-obacunoate. A novel norditerpene lactone, diosbulbine, was isolated from *Dioscorea bulbifera* Linn. Wightionolide isolated from *Andrographis wightiana* Arn. ex Nees was shown to be 17, 19, 20-trihydroxy-5 β, 8 α H, 9βH, 10α-labd-13-en-16, 15-O-lactone[9]. From the root bark of *Salacia prinoides* DC, six closely related triterpenes, all belonging to 1,3-diketo friedelane type, were isolated and their structures determined. *Clerodendrum inerme* Gaertn., a commonly used hedge plant, afforded a very potent insect antifeedant compound, the structure determination of which led to the reversal of the then accepted absolute configuration of clerodin. The antifeedent has been shown to be 3-*epi*-caryoptin. The absolute configuration of other insect antifeedant, ajugarins, was also reinvestigated[10]. Ailanthol isolated from *Ailanthus malabarica* DC has been shown to have the triterpene skeleton (20*S*)-4, 4, 8 β-trimethyl-14, 18-cyclo 5α, 13α, 14α, 17α-cholestane.

(4) Flavonoids

Corymbosin, isolated from *Webera corymbosa* Willd., was shown to be 5-hydroxy-7,3′, 4′, 5′-trimethoxyflavone through spectral and synthetic studies. Two new flavones, exoticin (3, 5, 6, 7, 8, 3′, 4′, 5′-octamethoxyflavone), and hibiscetinheptamethyl ether, were isolated from the leaves of *Murraya exotica* Linn. Three novel flavanones were isolated from *Unona lawii* Hk. f. & Thoms. In addition, structures were assigned to three flavones, unonal, unonal-7-methyl ether and isounonal, these being the only examples of flavonoids containing an aldehydic group. Two phenolic compounds, 3-formyl-1, 4, 6-trihydroxy-5-methyldibenzoyl methane and its 4-methyl ether, were isolated from the same plant. From the roots of *Garcinia talboti* Raiz., two biflavones, talbotaflavone and morelloflavone, were isolated and their structures determined[11]. Flavonoids and flavone glucosides have been obtained from *Pajanelia multijuga* P.D.C., *Ligustrum neilgherense* var. *obovata* C.B. Cl, *Angelonia grandiflora* C. Mor and

Melochia corchorifolia Linn. Certain collections of *Pueraria tuberosa* DC. afforded a new phytoalexin, tuberosin, having a hydroxypterocarpan structure[12].

(5) Coumarins and Chromones

Clausena heptaphylla Wt. & Arn. afforded two novel pyranocoumarins, clausenin and clausenidin. Their structures were established by spectral and synthetic methods. Syntheses of clausenin, xanthyletin, xanthoxyletin, alloxanthoxyletin and nordalbergin have been achieved. Peltophorin, isolated from the flowers of *Peltophorum ferrugineum* Benth., has been shown to be identical with bergenin. Surangin A and surangin B, isolated from *Mammea longifolia* (Wight) Planch & Triana, were shown to be highly alkylated 5, 7-dihydroxycoumarin derivatives[13]. Both exhibited high toxicity to the housefly and the mosquito larvae at low dosage. From the roots of *Clausena indica* Oliv., a novel coumarin, clausindine, was isolated and it was shown to have the structure 6-(2,2-dimethyl-cyclopropyl) furo [3,2-g] [1] benzopyran-7-one. A new coumarin, racemosin, isolated from *Atalantia racemosa* Wt. & Arn., was shown to be 5,10-di-methoxy-8, 8-dimethyl-2-oxo-2H, 8H-benzo [1,2-b:5, 4-b′]-dipyran on spectral evidence and through synthesis. *Dysophylla stellata* Benth afforded two phenolic ketones and stellatin constituted as 5-hydroxy-6,7-dimethoxy-2-methylchromone. Structures have been proposed for the rearrangement products obtained by the reaction of furanocoumarins with $AlCl_3$ in benzene.

(6) Quinones[15]

The structure assigned to islandicin, the colouring matter of *Panicillium islandicum* Sopp., was confirmed by an unambiguous synthesis. Syntheses of other anthraquinone pigments, *e.g.* lucidin, damnacanthol, damnacanthal, chrysophanol, rhein, emodin and physcion, have been achieved. Reactions of erythroaphins-*fb* and *sl*, the complex quinonoid colouring matters of the Aphididae, have been investigated. Detailed chemical studies were carried out on the pigments of stick-lac, the secretion of the insect *Coccus laccae*.

(7) Synthetic Chemistry

With a view to evaluating compounds for their anthelminthic and antiamoebic activity, derivatives were prepared by structure modification of embelin, a naturally occurring quinone. Also, benzimidazoles, benzoxazinones, imidoquinoxalines and phenylquinoxalines were synthesized. Some anthraquinone vat dyes were prepared and their fastness properties tested. A series of studies on the reactions of hindered phenols led to the preparation of the stable oxygen free radical 2, 6, 3′, 5′-tetra-*tert*-butyl-4′-phenoxy-4-methylene-2, 5-cyclohexadiene-1-one radical (galvinoxyl)[16].

The present and future research interests of Joshi relate to the chemistry of phytoalexins, insect antifeedant compounds and the pharmacology of diterpenoid alkaloids to study the structure-activity relationships.

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R S Kapil

Kapil has carried out systematic examination of a large number of Indian medicinal plants for biological activity and worked extensively on the structure elucidation of novel compounds, such as ankorine, alangimarckine and alangiside (monoterpene alkaloid glycoside) from *Alangium lamarckii*[1], seven new carbazole alkaloids from *Murraya koenigii*[2], monoterpene glycosides and roseoside from *Vinca rosea*, O-methylclausenol (C_{33} terpenoid), clausarin, clausmarins A and B from *Clausena pentaphylla*[3], five new macrocyclic diterpenes from *Anisomeles malabarica*[4], calyone, calyenone and precalyone from *Roylea calycina*[5], antidesmanol from *Antidesma menasu*, several new alkaloids from *Glycosmis mauritiana* and *Tabernaemontana divaricata*, a new dimeric coumarin and alkaloid from *Toddalia asiatica* and pterocarponoids from *Pueraria tuberosa*[6].

The natural products synthesized by Kapil include the alkaloids girinimbine, koenine, koenimbine, (*dl*)-mahanimbine, cyclomahanimbine, bicyclomahanimbine, mahanimbinine, mahanimbicine, bicyclomahanimbicine, O-methylmahanine, lansine, mupamine, glycocotrine-I, N-methylatalphylline and (*dl*)-macrostomine[7]. During the synthesis of murrayacine, Kapil developed a new method for the functionalization of aromatic methyl group with DDQ. The syntheses of coumarins like suberenol (by photoxygenation), coumarin Rr_8 (triple Claisen rearrangement), (*dl*)auraptenol (acid catalysed rearrangement), murrayone, 3-(3,3-dimethylallyl) xanthyletin[8], (*dl*)-3-(3,3-dimethylallyl) marmesin, (*dl*)-chalepin[9], clausarin[10] and (*dl*)-calusmarin A (biomimetic), the carbazole alkaloids, koenigicine[11], heptazoline and murrayaquinone-8, the pterocarponoids, anhydrotuberosin and tuberostan, have been novel and elegant in design and execution.

The most significant contributions of Kapil during the last two decades are on the biosynthesis of natural products. Commencing with the pioneering work on the biosynthesis of terpenoid indole alkaloids (in collaboration with Prof. A R Battersby), he has continued to blaze a new trail in this highly imaginative area of studies. Kapil has provided solutions for the biosynthesis of l-benzylisoquinoline derived alkaloids, such as boldine[12], isocorydine, papaverine, reticuline, coclaurine, tiliacorine, tiliacorinine, isococculidine and aristolochic acid[13]. He has shown by tracer experiments that the biosynthesis of 4-methylcoumarin proceeds through the intermediacy of ethyl acetoacetate while (*dl*)-chalepin originates from 7-(3,3-dimethylallyl) oxycoumarin involving a triple Claisen rearrangement. Kapil first proposed the

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mevalonoid origin of carbazole alkaloids and is currently solving biosynthetic problems with the aid of new techniques, such as CMR spectroscopy.

In the area of synthetic drugs, Kapil has carried out extensive work on the synthesis of new antifertility (nonsteroidal) and psychotropic (phenethylamines, tricyclic systems and cannabinoids) agents. Some of these compounds are under detailed biological evaluation. During the synthesis of secosteroids, he has observed a novel rearrangement leading to 1-(3-carboxybutyl)-2-(2-carboxyethyl) 3,4-dihydro-6-methoxnaphthalene[14] in a very elegant manner. Work on the Friedel-Crafts reaction of lactones led to the discovery of a single step synthesis of 10,11-dihydro-5*H*-dibenzo (*a*,*d*)-cyclohepten-5-one[15]. On the basis of this observation, he developed processes for the industrial production of two clinically useful drugs, amitriptyline and cyproheptadine.

Kapil's future plan of research includes biomimetic type syntheses of natural products and their biosynthesis. Another area in which he is deeply involved is the structure-activity relationship of estrogens[16].

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T R Kasturi

Spirodienones, a class of compounds which occur widely in nature, are important from the point of view of biosynthesis and have a fascinating chemistry. The term 'spirodienones' is used in this context to describe derivatives of cyclohexa-2,4-(**1**) and 2,5-dienones (**2**) in which carbon atoms 6 and 4 respectively are spirocentres. The topic is of current interest to many organic chemists and is an area for future development. Apart from their involvement in the biosynthesis of several compounds, the other reason why they have attracted the attention of organic chemists is that they undergo facile rearrangements to give thermodynamically more stable benzene derivatives[1].

The present discussion is restricted to spironaphthalenone derivatives. Our interest in this class of compounds dates back to 1970 and an account of our work in this area is presented below.

(1) Spironaphthalenones

Both 1- and 2-naphthols undergo oxidative coupling with O-chloranil to give spironaphthalenones. While 1-naphthol gives exclusively the spirodienone (**3**) on oxidation, 2-naphthol, unexpectedly, affords a mixture of the two spirodienones (**3** and **4**), indicating an unusual rearrangement[2]. It has also been shown that while oxydiphenols (**5**) undergo normal intramolecular oxidative coupling to give spirodienones (**3**), oxydiphenols (**6**) undergo oxidative rearrangement to give a mixture of the spirodienones[3] (**3** and **4**). In order to study the generality as well as substituent effects on this novel rearrangement, a number of substituted 1- and 2-naphthols were synthesized and their oxidative coupling reaction studied[4–6]. On the basis of this study, it was proposed that oxidation of 2-naphthol derivatives, perhaps, goes through the formation of spirocyclohexadienone intermediate (**7**), which could open up in either way to give a mixture of the spirodienones (**3** and **4**). The intermediacy of **7** is yet to be established through suitable trapping experiments. The conformation of the phenoxy group, the oxidation potential of the quinone and the substrate (the naphtholic and the phenolic part in the oxydiphenols) along with steric and electronic effects of the substituents could explain the observed results[7].

The spirodienones (**3** and **4**) are very stable to acid and heat. However, a novel isomerization of the spironaphthalenones (**3** and **4**) under photolytic condition has been observed[8]. A probable mechanism involving the formation of the spirocyclohexadienone intermediate (**7**) has been suggested.

Oxidation of Abel's ketone (**8**) and its derivatives with 2,3-dichloro-5,6-dicyano-

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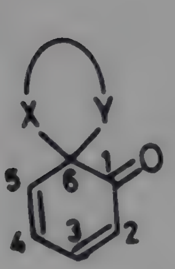
1,4-benzoquinone (DDQ) in benzene resulted in the formation of two isomeric products. One of them was the furanotropone (**9**) and the other was tentatively assigned the benzfulvene (**10**) structure based on its spectral data and some chemical transformation[9]. Further work has to be carried out to prove its structure beyond doubt.

(2) Bispironaphthalenones

Oxidation of bis-(2-hydroxy-1-naphthyl)-methane (**11**) with DDQ in benzene gave a mixture of bispironaphthalenones (**13** and **14**). An alternative synthesis of these compounds was achieved by condensation of (**12**) with 1-bromo-2-methoxynaphthalene followed by demethylation with BBr_3. Using this oxidation reaction, a series of bispironaphythalenones (**13** and **14**) have been synthesized and a suitable mechanism has been suggested for their formation[10].

The X-ray crystal structure analysis of the bispironaphthalenone (**13**) indicated that the C(2′)-C(3′) carbon-carbon bond (bond length 1.616 Å) was unusually long. In the mass spectra of these compounds, most of the fragments arise from the initial



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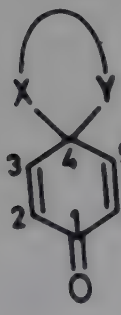

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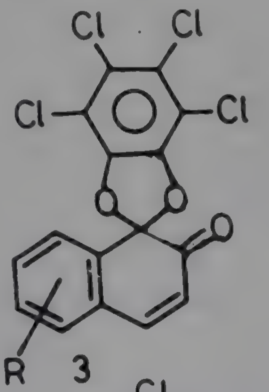

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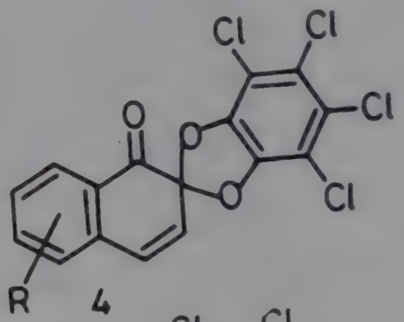

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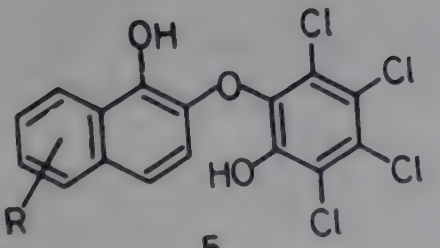

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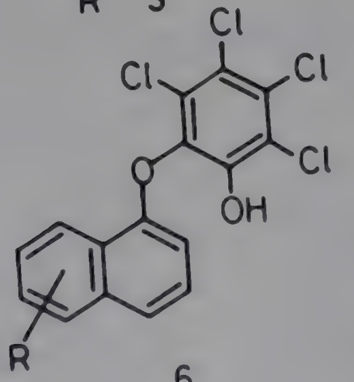

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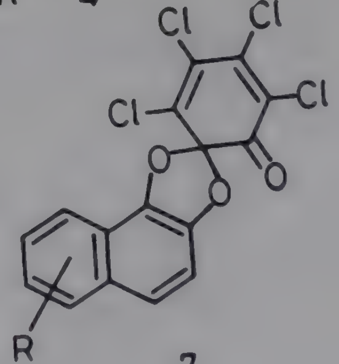

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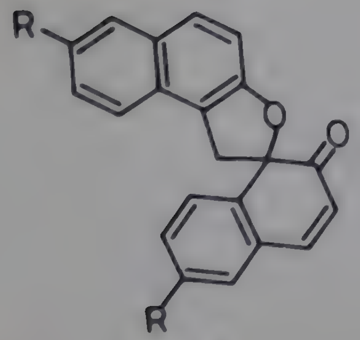

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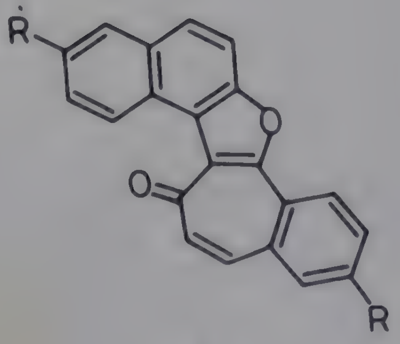

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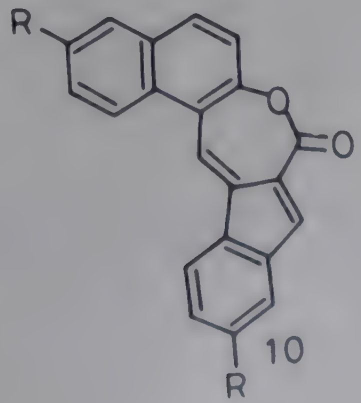

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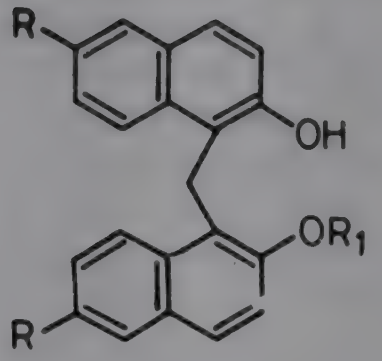
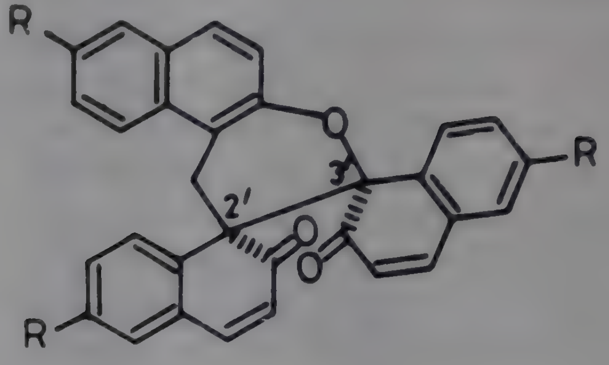


11, $R_1 = H$; $R = H$; Br ; t-But; methyl cyclohexyl

12, $R_1 = CH_3$; $R = H$



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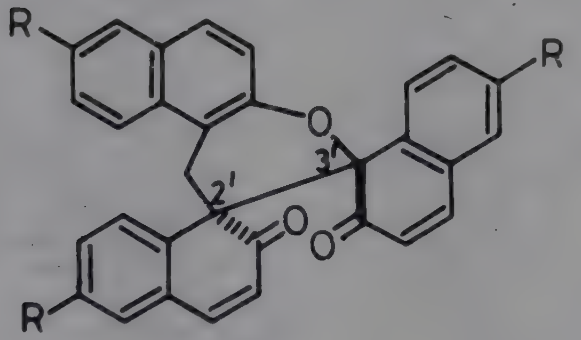
R = H ; Br ; t-But; methylcyclohexyl



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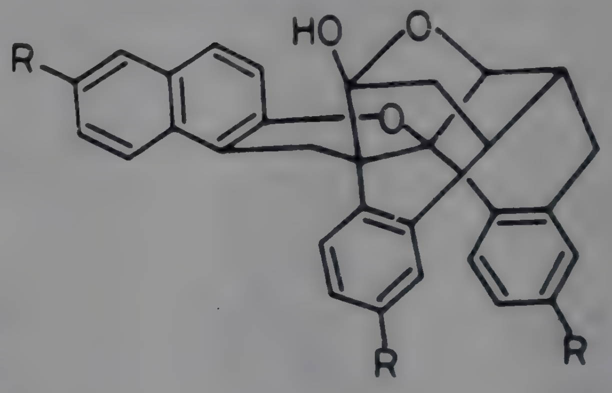
R = H ; Br ; t-But ; methylcyclohexyl



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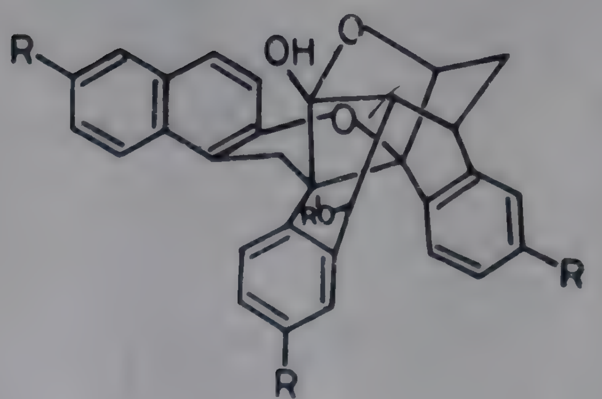

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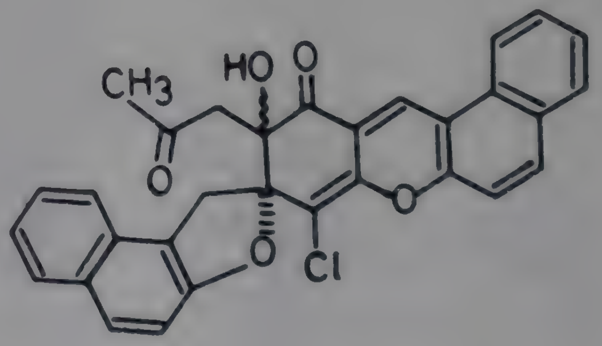

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cleavage[11] of this bond, indicating it to be very labile. This was further substantiated by hydrogenation and zinc acetic acid reduction, which led exclusively to the formation of 1-[(2hydroxy-1-naphthyl)-methly]-2-(2-hydroxy-1-naphthoxy)-naphthalene by hydrogenolysis of the C(2′)-C(3′) bond[10]. The labile nature of the C(2′)-C(3′) bond in bispironaphthalenone also became evident from the analysis of the photo[12] and pyrolysis products[13].

Another interesting reaction of

bispironaphthalenones (**13**) is the sodium borohydride reduction[14] in polar and non-polar solvents. The formation of products (**15** and **16**), characterized by NMR and mass spectral data, and confirmed in one case by X-ray crystal structure analysis, indicated the occurrence, for the first time, of a novel intramolecular Michael type addition.

(3) Polycyclic Spirodienones

A one-pot synthesis of a polycyclic diastereomeric spirodienone (**16**) having some resemblance to the antibiotic frederikamycin has been achieved by the reaction of 1-bromo-methyl-2-naphthol pyranyl ether with tetrachlorocatechol in acetone in the presence of anhydrous potassium carbonate. The reaction yielded the corresponing bromo compound when tetrabromocatechol was used in the above reaction instead of tetrachlorocatechol. When the reaction was carried out in the presence of ethyl methyl ketone instead of acetone, two pairs of diastereomers corresponding to the above spiro structure (**16**) were obtained. Based on this, a suitable mechanism has been suggested[15]. Further work to confirm these structures and to evaluate the biological activity of these compounds has to be carried out.

I wish to thank all my collaborators involved in the above work for their active participation.

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S S Katiyar

Katiyar has made significant contributions in the areas of enzyme reaction mechanisms, micellar catalysis, immunology and hybridoma technology during the last two decades. His outstanding achievements are discussed below under three main heads.

(1) Mechanism of Action of Enzymes of Lipid Biosynthesis and Structural Organization of Fatty Acid Synthetase Complex

In the biosynthesis of lipids, one of the frontier areas in biochemistry, Katiyar has done outstanding work[1]. For the first time he determined the kinetic mechanism of action of the enzyme fatty acid synthetase. The biosynthetic pathway of leading glucose to fatty acids is a prominent path in most of the organisms and the complete *de novo* synthesis of fatty acids is catalyzed by an enzyme complex fatty acid synthetase. This enzyme system consists of seven component activities, which are organized on two multifunctional polypeptide chains of equal molecular weight. Theoretical treatment for the overall reaction catalyzed by this enzyme has been developed by Katiyar and a new type of kinetic mechanism called "seven site ping pong mechanism" has been proposed by him[2,3].

Significant advances have been made by Katiyar in identifying the critical amino acids in the active sites of various component activities of avian and mammalian fatty acid synthetases. Investigations were directed towards the use of affinity labels and other specific reagents for the chemical modification of amino acids essential for the catalytic activity of the individual steps. These studies, coupled with controlled proteolysis with elastase[4], have been used by Katiyar as a tool to establish the structure-function relationship in fatty acid synthetase. For example, affinity lable S-(4-bromo-2,3-dioxobutyl)-coenzyme A was used[5] to establish the presence of two β-ketoacyl synthetase activities and two 4′-phosphopantetheines per mole of the pigeon liver fatty acid synthetase. Further, Katiyar established the presence of a lysine at the enoylacyl reductase and an arginine at the β-ketoacyl reductase site of fatty acid synthetase using pyridoxyl -5′-phosphate and phenylglyoxal respectively, as modifying agents[6].

Important contribution have been made by Katiyar in determining the sequence around the sites which covalently bind the intermediates to the enzyme activities involved in the synthesis of fatty acids. Exhaustive studies were carried out by him in purifying the peptides containing the active sites of fatty acid synthetase with [14C]-acetyl-CoA and then hydrolyzing it with various proteolytic

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enzymes like pepsin, trypsin, pronase, thermolysin, carboxypeptidase, etc.

Recently, Katiyar employed immunochemical methods for the estimation of active and inactive species of rat liver fatty acid synthetase in animals in different nutritional and hormonal states[7]. These studies have established the important result that insulin and triiodothyronine regulate the synthesis of fatty acid synthetase protein and insulin regulates the enzyme activity[8].

(2) Hybridoma Technology (Monoclonal Antibodies) as Structural Probes

From recent immunological studies, Katiyar has found[9,10] that an antibody prepared to a site on one enzyme (a dehydrogenase with an NADPH binding site) will in many instances bind to the same site (an NADPH binding site) on a totally unrelated enzyme. Since this phenomenon is quite widespread, it is proposed to produce polyclonal antibodies that are site-specific to various nucleotide binding regions of several enzymes. Katiyar plans to separate and enrich the site-specific antibodies by immunoaffinity chromatographic procedures.

In order to capitalize on the potential of site-specific antibodies, Katiyar has initiated the production of monoclonal antibodies to pigeon liver fatty acid synthetase by hybridoma technology. With the monoclonals, he plans to extend the studies on the cross-reactivity of the antibody with various antigens. These antibodies would be used for developing procedures to purify enzymes/proteins that are difficult to purify because of contaminating proteins or the presence of only small amounts of the enzyme. These monoclonal antibodies could also be used in conjuction with other methods to establish the amino acid sequence of the peptide chain of the antigen that binds the antibody. Katiyar also plans to use the monoclonal antibodies as structural probes to determine the structural organization of the two polypetide chains that form the complex enzyme.

Katiyar has research programmes that are directed towards increased utilization of the immense potential of monoclonal antibodies as diagnostic tools. In this direction, Katiyar plans to generate monoclonal antibodies to α-fetoprotein and myosin. A suitably selected monoclonal antibody to myosin when properly labelled with a radioisotope can be a valuable tool in assessing the damage done to the heart muscle during a heart attack. Similarly, a monoclonal antibody to α-fetoprotein can be used to detect cancer of liver in the initial stages.

(3) Elucidation of Mechanism of Catalysis of Surfactant Micelles

Study of catalysis of inhibition of reactions in the presence of micelle-forming amphiphiles has become an area of great significance in recent years. The observation of substrate specificity, saturation kinetics, the lack of homogeneity in submicroscopic surface of micelles as well as enzymes and the fact that both enzymes and micelles bind the substrate in a noncovalent manner prior to the catalytic step led to the belief that the reactions catalyzed by the micelles could be viewed as models of enzyme catalyzed reactions.

Katiyar pioneered in India a systemic study of the micelle catalyzed reactions with a view to giving a quantitative interpretation to the data. The systems chosen for these investigations were: (i) the reactions of carbonium ions with nucleophile[11], (ii) transimination reactions of azine bis-barbiturate, barbituryl azine indandione and azine bis-barbiturate, barbituryl azine indandione and azine bis-inandione[12], and (iii) acid and base hydrolysis of azine bis-inandione, barbituryl azine inadandione and other Schiff bases[13]. The reason for choosing these systems was that the hydrophobic and electrostatic nature of the substrate could be varied according to the requirements of the experiments. The inhibition and catalysis of the reactions of triphenylmethyl carbonium ion with nucleophiles in the presence of sodium dodecyl sulphate and cetyl trimethylammonium bromide micelles have been interpreted by Katiyar quantitatively by studying the distribution of the substrate in micellar and bulk phases, rate constants at the reaction site, and binding constants of the substrate with the respective micelles.

The effect of added counter-ions on the micelle catalyzed reactions was not well understood. Katiyar has proposed a model[14] for understanding and interpreting the effects of additives on micellar catalysis and inhibition. The mathematical formulation of Katiyar is capable of explaining the experimentally observed features of the effects of various parameters, viz. concentration of surfactant, reactant, and counter-ions on the micelle catalysed and inhibited reactions. The validity of this model has been examined by testing the derived equation for the analysis of the data available in the literature, as well as his own data.

The earlier models of Bunton, `Srirahama, Berezin and Romsted did not take into consideration one or more of the following factors: (i) neutralization of charges on the catalytic micelles by counter-ions, (ii) replacement of reactant ions around the catalytic micelles by inert counter-ions and vice versa as a result of variation in the concentration of these species in the reaction system, (iii) possible changes in the aggregation properties of the detergent to form catalytic micelles in the presence of electrolytes and substrate, (iv) differences in the relative overall effectiveness of various counter-ions in altering micellar effects, and (v) dependence of the degree of counter-ion binding to the micelles on the nature of the counter-ion. Katiyar's formulation takes into account most of these factors and has shown applicability in most of the reactions studied so far[15,16].

Elegant series of planned experiments have been used by Katiyar to demonstrate[12] the hydrophobic interactions between the substrate and micelles—interactions which are responsible for the extreme inhibition of reactions in the presence of micelles. For example, it has been shown[12] that the cationic micelles of CTAB inhibit the acid catalyzed transimination reactions of azine-bis-barbiturate, and azine-bis-barbiturate, barbituryl azine indandione, and azine-bis-indandione with semicarbazide by factors of 1,2,14 and 113 respectively. This magnitude of inhibition follows the increasing order of substrate hydrophobicity.

Katiyar has also studied the reactions of various triphenylmethyl carbonium ions in acid and alkaline media, as a model system to investigate the salt and solvent effect on the ion-ion and ion-molecule reactions[17,18]. With this work, Katiyar has been able to resolve the existing controversy about the nature of the reaction of these carbonium ions with hydrogen ions. A detailed proteolytic scheme for the reaction, taking into account all the species in the solution, has been suggested and the ion-molecule nature of the reaction has been proved convincingly.

Katiyar did outstanding work in India in initiating the Huckel molecular orbital calculations on the Schiff bases and α,β-unsaturated ketones and correlated $E_{1/2}$'s with the energy of lowest molecular orbitals. In this area of organic polarography, several important contributions have been made by Katiyar. Mechanisms of reduction of Schiff bases, α,β-unsaturated ketones[19], oxymercurated allenes[20] and heterocyclic N-oxides, have been established at the dropping mercury electrode. The existing controversy in the mechanism of reduction of α,β-unsaturated ketones had been resolved by him. It has been demonstrated that the first electron is accepted by the ethylenic carbon atom. The influence of substituents on half-wave potentials of the above-named organic compounds was investigated experimentally.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S V Kessar

Significant new synthetic methodology has been introduced in the areas outlined below. Total synthesis of a large number of natural products has been accomplished and mechanistic pathways for some novel transformations have been delineated.

Synthesis of Steroidal Alkaloids, Sapogenins and Azasteroids

An approach to the widely occurring spirostane, spirosolane and solanidane ring systems which had defied synthesis for a long time has been elaborated. It allows stereo control at each of the five generated chiral centres and has resulted in the synthesis of representative members of all the three classes like diosgenin, yamogenin, kryptogenin, harthogenin, septrumgenin, cholesterol, solanidine, demissidine, tomatodine and solasodine.

Total synthesis of a number of azasteroids of pharmacological interest has been carried out through ingenious routes.

Benzyne Cyclization

A new benzyne-mediated cyclization leading to condensed polynuclear systems has been developed. Its versatility has been demonstrated by the synthesis of a variety of heterocycles, including alkaloids like nitidine, avicine, chelerythrine, fagaronine, perlolidine, domesticine and cryptauwoline. The mechanism of the intriguing ring closure of the Schiff bases, with known unfavourable *trans* geometry, has been investigated in depth. In literature, this reaction is being referred to as the 'Kessar benzyne cyclization' and it has formed the basis of an invited article in the '*Accounts of Chemical Research*'.

Photochemistry

The first synthesis of penta-oxygenated benzophenanthridine alkaloids was achieved through a key photoinduced dehydrohalogenation step. Similarly, the only successful synthetic route to *trans*-7-hydroxyaporphines was devised on basis of the concept of conformational locking of the photosubstrate. A new synthetically useful phototransformation of α-ketoimines has been uncovered. Its mechanism was explored with extensive labelling experiments which reveal a fascinating transposition of substituents. Photoinitiated electron transfer from amide and imine derived carbanions has been investigated and the ensuing reactions utilized for the synthesis of alkaloids like cherylline and corynoline.

Very recently, a simple but highly effective procedure for regio control in partial alkylation of polyphenols has been devised on the basis of reverse dianion selectivity. It is likely to find wide application in natural product synthesis.

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Future Directions

Exploration and development of novel ground and excited state transformations of synthetic potential continues to be the main research interest of Kessar. For this purpose, work on the utilization of special properties of α-silyl amines has been initiated.

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C L Khetrapal

In recent years, my research contributions have been mainly in the area of nuclear magnetic resonance (NMR) of oriented systems in general and in mixed liquid crystals in particular. I have to my credit over 150 research papers and 10 books, reviews and monographs published by Academic Press, Springer-Verlag and the Royal Society of Chemistry.

Novel NMR Studies on and in Mixed Liquid Crystals

During recent years, exciting discoveries and special contributions have been made in the use of mixed liquid crystals of similar and opposite diamagnetic anisotropies. This work has given rise to enormous new applications of NMR spectroscopy. To mention a few, the experiments led to the discovery of a method to study chemical shift anisotropy without the use of a reference compound or without change in experimental conditions, the determination of NMR spectral parameters which otherwise cannot be determined from the spectra of oriented systems, precise determinaion of spectral parameters, and the determination of molecular structure with minimal distortions. As an outcome of such experiments, a method to determine the diamagnetic anisotropy of liquid crystals has been proposed by a group of scientists in Switzerland. The theory underlying such experiments has also been developed by us. The work has generated considerable research activity in several developed countries, such as Switzerland, Denmark, USA and Canada. The method for the determination of chemical shift anisotropy propsed by me and my colleague using mixed liquid crystals of opposite diamagnetic anisotropies has been named the NEMIX method in the scientific literature by the Swiss scientists who have compared this method with others and have found that this is the best method available so far[1–5].

New Applications of NMR of Oriented System

From 1967 onwards, I started working in the new area of research involving NMR spectroscopy of oriented systems and my contributions in this area are well recognized in the scientific literature. They opened the field of NMR spectroscopy of oriented systems to researchers in the chemical and biological sciences involving the determination of structure, conformation and function of molecules. I was the first to (a) apply the technique to problems of biological importance and the larger molecular systems[6,7], (b) demonstrate the use of two-dimensional NMR to oriented systems to derive information which otherwise is difficult to obtain in such cases[8,9], (c) evolve methods for the study of weak molecular interactions, ring

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puckering vibrations and inorganic complexes, and (d) propose new methods for the determination of covalent and van der Waals radii[10]. I demonstrated for the first time the use of an electric field applied perpendicular to the magnetic field in NMR spectra of oriented systems so as to produce a switchover of the optic axis of the liquid crystal by 90°[11]. These experiments, thought difficult to perform, have several new applications and potentials. I was the first to predict the isotopic effects on molecular orientation and demonstrated the influence of isotopic substitution on molecular structure[12]. I reported for the first time the use of near magic angle sample spinning and the multipulse sequence for the change of molecular orientation as desired. Such experiments have great potential in the use of the technique of NMR of oriented molecules to large systems of chemical and biological importance. We gave the bond polarization hypothesis to govern the preferred conformation of molecules. The hypothesis has been tested in a large number of systems and has been used widely[13].

Methods for the Determination of Aromaticity and Study of Weak Molecular Interactions

During initial years of research career in early 1960's, I proposed new methods for the study of aromaticity and weak molecular interactions using NMR dilution shifts[14].

Books and Reviews

The books, reviews and monographs written/edited by me have been very well accepted and have high science citation indexes. For example, my contribution in *NMR—Basic Principles and Progress*, Vol. 1 (Springer-Verlag) was selected as a Citation Classic in 1983. One of my papers[15] has been cited over 150 times. I am on the International Editorial Board of *NMR—Basic Principles and Progress* and on the list of Reporters of *Specialist Periodical Reports: NMR*, published by Springer-Verlag, West Germany and the Royal Society of Chemistry, England[16].

Future Plans

Research aimed at discovering new applications of NMR spectroscopy of oriented systems and new methods for the simplification of the spectra will be continued.

The idea to use the 'Near Magic Angle Sample Spinning', will be explored to determine the structure and conformation of biologically important molecules. The use of multiple quantum transitions for such purposes will also be explored.

The hitherto unexplored area of the use of chloresteric liquid crystals in NMR will be tackled. Lytropic liquid crystals which resemble biological membranes will be used to study their behaviour when mixed with systems of opposite diamagnetic anisotropies.

Theoretical work involved in the estimation of 'local effects' in the earlier proposed NEMIX method will be undertaken. The bond polarization hypothesis proposed earlier will be used for the determination of structure and conformation of molecules of biological importance.

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V Krishnan

Krishnan's research contributions encompass the area of inorganic biochemistry, with special emphasis on the development of biomimetic model systems. The major objective of his work has been to evolve a basic understanding of the role and function of metal ions in biological reactions. Model reactions involve laboratory simulation of photosynthetic function, cation transport in mitochondria, cytochrome c oxidase function, cytochrome P-450 for oxygen activation and 'tetramer heme' for reversible oxygenation. The current research efforts follow three directions: (i) development of molecular assemblies for photosynthetic energy and electron transport, (ii) a study of coordinative and molecular interaction involving chlorophylls, porphyrins and crown ethers, and (iii) development of chromophoric ionophores for the study of cation transport across membranes.

A novel crown ether-porphyrin assembly, mesotetrakis (benzo-15-crown-5)-porphyrin, has been synthesized. These cavity bearing porphyrins undergo dimerization on complexation with K^+, NH_4^+ and Ba^{2+} ions, providing first examples of noncovalently linked dimers. These supermolecular entities have an eclipsed sandwich geometry with interplanar distance of 4.0 Å. They display fast intersystem crossing efficiencies and show remarkable resemblance to the reaction-centre complex of the natural photosynthetic system. In a parallel study involving singly linked porphyrin dimers, $MP\text{-}OCH_2(CH_2\text{-}O\text{-}CH_2)_nCH_2OPM$, where $M = Co^{2+}$, Cu^{2+}, Zn^{2+} and 2H and $n = 0, 1, 2$ and 3, it has been demonstrated that the efficiency of singlet energy transfers from one porphyrin centre to another varies with inter-chromophore distance and the maximum efficiency is achieved when the two porphyrin planes are separated by 8.0 Å. A novel way to fold these linear bisporphyrin systems by introducing a spacer organic molecule to promote cooperative interaction between two chromophores has been accomplished. These dimers exhibit photophysical and photochemical properties very close to those observed for reaction-centre complex of bacterial photosynthetic systems. The importance of folded geometry in the case of excitation energy transfers was elucidated from another study involving porphyrins with podand side arm and terminating with an electron acceptor moiety. A critical side arm distance of 8.0 Å favours the formation of folded conformers. Intra-molecular photochemical electron transfer systems involving porphyrins covalently linked to several nitroaryl and quinone moieties at various distances and orientations have been developed. It has been demonstrated

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that the incidence of light radiation leads to the formation of radical pair. It has been found that the generation of radical-pair proceeds much faster than the recombination process and both these reactions are governed by orientation factors. A critical distance of 8.0-10.0 Å with coparallel orientation of the donor and acceptors is found to be essential for ultrafast light induced radical pair production. It has been shown that the maximum energy that can be stored by charge-separation in porphyrin-nitroarene systems is ~ 1.6 V for an excitation energy of 1.9 V (650 nm). These model systems are found to be much superior to porphyrin-quinone systems and are closely analogous to the quantum yields obtained in the natural photosynthetic process.

The second direction is towards the establishment of the nature of interactions between two neutral molecules and the orientational features in the resulting complexes. The charge-transfer interaction is recognized as one of the major forces of stabilization in the complexes formed by crown ethers, chlorophyll, pheophytins, porphyrins and their metal derivatives with diverse organic acceptors of varying electron affinity. The enthalpy changes of complexation are diagnostic in ascertaining the extent of coordinative *vis-à-vis* molecular interactions in such complexes. Interestingly, however, when a potential donor N-heterocyclic group is covalently attached to a porphyrin, enhanced singlet emission quantum yields are observed due to the existence of intramolecular charge-transfer resonance. These ground state charge transfer systems are found to be responsible for the ultrafast excited state electron transfers.

The third direction involves a study of several crown ether-chromophore systems. These contain either a benzo-15-crown-5 or a dibenzo-18-crown-6 moiety covalently linked to MN_4 (metal-schiff base) chromophore or porphyrinic groups. The crown ether-porphyrin assembly displays high selectivity of complexation of intracellular K^+ ions. Moreover, they function as effective uncouplers of oxidative phosphorylation in rat liver mitochondria. The metal ions in the porphyrin cavity are shown to inhibit oxidative phosphorylation. An advantage of these systems as ionophores is that they provide valuable fluorescence probes for K^+ ions. Development of systems for selective cation complexation through initiation of light would form the future endeavour in this direction.

Other lines of research investigations are concerned with the development of biomimetic models bearing tetrapyrrole systems to elucidate heme function, *tris* porphyrin systems to duplicate the singlet-singlet energy transfers akin to the antenna protein in photosystems, porphyrins linked to thiol groups for cytochrome activity. Many of these photoprocesses have been investigated in organized assemblies. An elegant and novel method has been developed for probing into the kinetics of metal incorporations into tetrapyrrole pigments using singlet emission method. It has been demonstrated that the intra-micellar and inter-micellar quenchings of the singlet emission of chlorophylls and porphyrins essentially proceed through CT complexation and are governed by diffusional features of the reactants and products. The latter bears a simple relationship to the nature of organized assemblies and governs the excited state redox potentials. These investigations form the future direction of research.

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A B Kulkarni

Kulkarni's emergence as a front-ranking organic chemist can be attributed to his undoubted ability to accept challenging problems in synthetic organic chemistry and chemistry of natural products at an early stage in his research career. The following is a brief account of some of the problems handled by Kulkarni and his group at the National Chemical Laboratory, Pune; Institute of Science, Bombay; and the Department of Chemistry, University of Bombay.

(1) Leucoanthocyanidines and Related Compounds

Leucoanthocyanidines occur as such in nature and are the building units of phlobatannins. They play a significant role in the biogenesis of flavanoid pigments and hence their importance. The synthesis of flavan-3,4-diols is rendered interesting by the presence of three asymmetric centres and the possible four racemates which could occur in nature. This formed the basis of an elaborate programme of research which entailed developing methods for the selective synthesis of different racemates, stereochemical studies, synthesis of naturally occurring compounds and related investigations. The synthesis of four recemates of 6-methyl-4′-methoxyflavan-3,4-diol constituted the core of these studies.

Judicious use of metal hydrides and other hydrogenation catalysts helped Kulkarni and coworkers to develop methods for the synthesis of a number of naturally occurring compounds, such as fustin trimethyl ether, dihydrorobinetin tetramethyl ether, guibourtacacidin dimethyl ether, leucorobinetinidin tetramethyl ether, mollisacacidin trimethyl ether, etc.

An interesting offshoot of the above investigations was a method evolved for the synthesis of isomeric catechins. The method involved reduction of flavonol benzyl ethers with appropriate substituents by $LiAlH_4$ and hydrogenation of the complex *in situ* over Raney nickel to obtain the corresponding 3-benzyloxyflavan derivatives, which were further debenzylated to the corresponding catechins.

As an adjunct to studies on flavan-3,4-diols, detailed investigations were undertaken on the stereospecific synthesis of 3-halogenoflavanones. N-Bromosuccinimide and cupric bromide were found to be effective reagents for introducing bromine selectively in C_3 position in flavanones.

Proanthocyanidines occur widely in nature and considerable interest has been evinced in the isolation of these compounds and their structure

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elucidation. Kulkarni and coworkers reported a novel synthesis of dimeric proanthocyanidines by reaction of substituted flavan-4-ols with PBr_3 and treatment of the product *in situ* with collidine. The structures of the proanthocyanidines were substantiated by mass, UV, IR and PMR spectral data.

(2) Synthesis of Tetracyclines and Naphthacenequinones

The naturally occurring tetracyclines represent a class of broad spectrum antibiotics of great commercial and therapeutic importance. Since the compounds first came into prominence, a number of their derivatives have been isolated from nature or made by chemical modification of the natural metabolites. Tetracyclines are octahydronaphthacene derivatives and hence the chemistry of hydronaphthacenes attracted the attention of Kulkarni and coworkers, who commenced their investigations on the synthesis of hexahydronaphthacenes and naphthacenequinones in the year 1957. Tetralones, particularly α-tetralone 3-carboxylic acids, were employed to synthesize hydronaphthacenes having rings B and C hydroaromatic. The choice of appropriate substituents in the intermediates used enabled Kulkarni and coworkers to synthesize hydronaphthacences with a majority of the substituents present in the natural tetracyclines in the appropriate positions. Though the synthesis of the desired octahydronaphthacenes presented difficulties, the above approaches to the synthesis of tetracyclic compounds then held potential for the preparation of pretetramide precursors to natural tetracyclines, which have assumed importance recently. The stereochemistry of the tetralone-3-carboxylic acids employed depends upon the geometry of the itaconic acid derivatives obtained by Stobbe condensation of aldehydes and ketones with succinate esters. In the latter case, mixtures of *cis* and *trans* compounds are formed and separation of the isomers presents formidable problems. Besides, rationalization of the formation of isomers in varying yields is difficult. Methods were evolved for near quantitative separation of the Stobbe condensation products of some ketones taking advantage of the differences in solubilities of their sodium salts in water. Concepts of conformational analysis were employed for deciding the stereochemistry of the Stobbe acids and for preferential formation of certain isomers.

(3) Studies in Phenyltetralin Group of Lignans

Lignans are naturally occurring compounds which represent a dimeric stage intermediate between monomeric propylphenol units and lignins. Nordihydroguaiaretic acid, pinoresinol, conidendrin, podopyllotoxin, sikkimotoxin, lynoresinol, peltatins, etc. may be cited as a few examples of the important phenyltetralin group of lignans. Since some of the compounds exhibit tumour damaging properties, they have attracted considerable attention as potential anticancer drugs. Synthetic work in the field was started in Kulkarni's laboratory wtih a view to evolving stereospecific methods for the synthesis of this group of compounds. After preliminary studies which dealt with choice of intermediates, the synthesis of sikkimotoxin was undertaken. The synthesis of an isomer of sikkimotoxin was reported independently by Schreier and by Kulkarni and coworkers in 1963-64, employing 3 carboxy-4-(3′, 4′, 5′-trimethoxyphenyl)-6, 7-dimethoxy-1-tetralone. The former effort was backed by an industrial establishment.

Galbulin and isogalbulin are constituents of Australian species *Himantandra baccata* Bail. The synthesis of an isomer of galbulin was carried out. Based on chemical evidence, PMR data and correlation studies, 3,4-*trans* and 2,3-*cis* stereochemistry was assigned to the compound. The synthesis of a number of phenyl tetralin group of lignans was also carried out. Among these are lyoniresinol dimethyl ether, diastereoisomer of isoolivil dimethyl ether, isolariciresinol, etc.

(4) Chemistry of Natural Products

Apart from contributions to the chemistry of pristimerin, which were made at an early stage in Kulkarni's career, the following plant species were investigated in the laboratory.

(i) *Cassia occidentalis Linn*: The acid hydrolysed extractives of the plant furnished islandicin, helminthosporin, xanthorin, chrysophenol, α_3-sitosterol and a xanthone, which was named cassiollin, in addition to emodin and physcion, the known constituents of the sepcies. Cassiollin was initially identified as 1,7-dihydroxy-5-methoxycarbonyl-3-methylxanthone. However, subsequent investigations led to its structure being modified to the 7-methoxycarbonyl analogue, pinselin, known in literature. As an adjunct to studies on cassiollin, extensive synthetic work on xanthones was carried out in the laboratory. Thus, the synthesis of 5-carbmethoxy-1, 7-dimethoxy-3-methylxanthone was accomplished, and the compound was found to be different from the dimethyl ether of cassiollin. Subsequently, an elegant synthesis of 8-carbmethoxy-1, 7-dimethoxy-3-methylxanthone, the dimethyl ether of the naturally occurring pinselin/cassiolin, was carried out. The synthesis of masuaxanthone 'A', viz. 1,5-dihydroxy-3-methoxyxanthone, a constituent of *M. ferrea*, was also achieved.

(ii) *Chemical investigation of Aeginetia indica Linn*: The ethanol extract of the plant furnished aeginetic acid and aeginetolide, in addition to β-sitosterol. The petroleum ether extract furnished apocarotenoid polyenes. Structure elucidation of the compounds was based on extensive UV, IR, mass, PMR and ORD data.

(iii) *Chemical constituents of Polyporus porrectus (Murr.)*: The petroleum ether extracts of the wood rotting fungus furnished four compounds, which were identified at α-hydroxytetracosanoic acids, 1,4-dimethoxy-2,3,5,6-tetrachlorobenzene, cycloartenone and a mixture of phytosterols.

(iv) *Study on Sida carpenifolia Linn from Malvaceae family:* The chloroform extract of this perennial shrub gave a compound which was identified as ecdysterone. Though the isolation of the latter from plants had previously been reported by several workers, its presence in Malvaceae family was encountered for the first time.

(v) *Studies on Tricholepis glaberrima DC*: Investigations on the aerial parts of this plant species afforded two homologous series, one of alkanes (C_{31} to C_{35}) and the other of wax esters (C_{52} to C_{56}), stigmast-22-en-3-o1 and quercetin-3-rutinoside.

(5) Studies in Sphingolipids

The chemical composition of the brain has been studied since the end of the eighteenth century, but major advances in the chemistry of sphingolipids are of comparatively recent origin. Sphingolipids are lipids derived from the parent base, sphingosine (d-erythro-1,3-dihydroxy-2-amino-4-trans-octadecane), or a closely related compound. These sphingolipid long chain bases are present in mammals as components of sphingomyelins, glycosyl, ceramides, cerebroside sulphates and gangliosides. Kulkarni and coworkers developed a method for the synthesis of substituted C_{14}-dihydrosphingosine.

(6) Studies in Steroids

17 α-Methyl-17-hydroxyandrosta-1, 4-diene 3-one (methadienone) is commercially important and is generally encountered with its 1,4,6-trienone derivative. Using sodium metabisulphite, a convenient method for the separation of these two compounds was standardized.

Judicious use of chromatographic procedures and UV and PMR spectral studies formed the basis of these investigations. In connection with this work, which entailed analysis of components, a detailed study on pyridine-induced shifts in PMR spectra of conjugated ketones was made and the results were compared with the benzene induced shifts. As an adjunct to this study, pyridine-induced PMR shifts in tertiary alcohols were also investigated.

2,2-Dibromo-2-cyano-N,N-dimethylacetamide was found to be an effective an preferential brominating agent for monobromination at α carbon atoms of ketones. The reagent holds promise as a brominating agent for steroids and other systems as nuclear bromination does not occur and byproducts are not obtained.

(7) Studies on Reductive Methylation of Ketones Containing Nitro Functions

Introduction of a dimethylamino group was a problem faced by Kulkarni and coworkers in their studies on hexahydronaphthacenes. A method for introducing the function in molecules containing keto function was develped using formaldehyde and Raney nickel. The latter was extended to the synthesis of a large number of compounds, including xanthones and hexahydronaphthacenediones.

(8) Synthesis of Fluorenones and Dibenzothiophenes

During the course of an investigation on the Stobbe condensation reaction on 2-bromobenzophenones, using alkoxides, the formation of highly coloured compounds free from bromine was encountered. Further study revealed these compounds to be substitued fluorenones formed under nucleophilic conditions.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P T Manoharan

For ions of the transition metals, the electron spin resonance (ESR) spectral characteristics are governed by the symmetry of the environment and can be described by the spin Hamiltonian

$$\mathcal{H} = \beta\vec{S}\cdot\mathbf{g}\cdot\vec{B} + \vec{S}\cdot\mathbf{D}\cdot\vec{S} + \vec{I}\cdot\mathbf{A}^{M}\cdot\vec{S} + \vec{I}\cdot\mathbf{P}\cdot\vec{I} - \beta_N\vec{I}\cdot g_N\cdot\vec{B} + \vec{I}^{L}\cdot\mathbf{A}^{L}\cdot\vec{S}$$

of which the energy levels associated with hyperfine part of the interaction are given by the last four terms, wherein $\mathbf{A}^{M}$ refers to the metal hyperfine tensor arising from the interaction between the magnetic moment of the unpaired electron with that of the nucleus. While metal hyperfine interaction tensor along with the g-tensor yields information on the nature of the ground state, the ligand hyperfine tensor can adequately describe the delocalized nature of the molecular orbitals. [Abragan A & Bleaney B, *Electron paramagnetic resonance of transition ions* (Clarendon Press, Oxford) 1970].

Our own work in this area of delineation of the molecular wavefunction started from the description of the electronic structure of metal nitrosyls[1-3] where not only the metal hyperfine tensor but also the ligand hyperfine tensor from ^{14}N of NO allowed the identification of not only the ground state but also the excited states with a great authenticity. A similar situation existed in biologically relevant molecules, namely the tetraphenyl porphyrins of copper and silver[4]. Here, it is the combined presentation of the metal and, ligand hyperfine tensors along with those of the g-tensors which permitted the identification of the ligand field spectrum, which otherwise would not have been possible. A comparison between a $3d^9$ Cu^{2+} and a $4d^9$ Ag^{2+} brings out the larger delocalization in the latter ion. Later, these results are to become very relevant in the reconstituted hemoglobins containing Cu^{2+} ion as a probe in place of Fe^{2+}.

A comparative study of hemoglobins reconstituted with Cu^{2+} before and after treatment with carboxypeptidase-A revealed the inadequacy of simple wavefunctions containing only the orbitals from the metal and nearest neighbour ligand orbital[5], such as

$$\Psi = c_M\Psi_M + c_L\Psi_L.$$

This necessitates the separation of the transition ion matrices into two groups: (i) simple complex ions, such as $CrOF_5^{2-}$, $MoOF_5^{2-}$, etc. where the unpaired electrons do not see much beyond the periphery of the immediate ligands, and (ii) complexes containing multidentate ligands, such as porphyrins, where the radial attenuation of spin density from nitrogen onwards would leave sizeable densities on

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carbons until it reaches the exterior protons. This is the reason that the total unpaired densities in the group (i) systems are shared by the metal and the ligand[6–11], while in group (ii) type matrices, spin densities beyond the coordinating ligand are substantial.

Metal hyperfine interaction tensor also becomes a monitoring probe to identify some finer details in the lattice. The unambiguous determination of orientation of the magnetic tensor components with respect to the molecular axis, relative signs of hyperfine parameters and analysis of forbidden transitions based on a complete diagonalization of the spin Hamiltonian brought out the importance of both the quadrupolar and nuclear Zeeman contributions[12].

It is well known that the general theory of magnetic resonance relates the total width (Γ) of the exchange narrowed line to the amplitude of local (dipolar and hyperfine) fields and for $kT \gg J$ to Fourier components of spin correlation functions.

$$\Gamma_{\text{total}} = \Gamma_{\text{hyperfine}} + \Gamma_{\text{dipolar}}$$

A knowledge of hyperfine fields as measured from a paramagnetic system in a diluted lattice along with the dipolar field calculated on the basis of a known crystal structure of the pure magnetic system could yield information on exchange interactions in pure lattice[13].

Also, a comparison of EPR of a simple salt such as $(NBu_4)_2$ $Co(mnt)_2$ with that of CT salt, viz. $(NMP)_2Co(mnt)_2$, reveals a large change in the hyperfine tensor values, which is ascribed to charge transfer from a donor to acceptor as existing in the latter donor-acceptor complex.

Now since we have looked into the depths of hyperfine interactions from metal centres, more emphasis has to be given hereafter to the lignad and its periphery in group (ii) systems mentioned above. However, in these cases it is possible that the typical ESR lines may be inhomogeneously broadened, severely limiting the resolution. Such systems will be broadly classified into (a) single crystal, and (b) polycrystalline or amorphous solids or frozen solutions. In order to extract information about the small hyperfine interactions from these systems, electron nuclear double resonance (ENDOR) would be employed where single crystals could be made. However, in non-oriented solids, instead of observing well resolved lines, one may observe the so-called 'matrix' ENDOR lines. Though in principle it is possible to perform a detailed ENDOR lineshape analysis to get information on isotropic and dipolar couplings, it is feared that such analysis will not be fruitful. A more promising method for such investigations in non-oriented samples would be the pulsed ESR technique with the nuclear modulation effect. This nuclear modulation arises due to the electron-nuclear dipolar interaction. Analysis of such electron spin echo modulation in the time domain would be very fruitful both for single crystals and polycrystalline media.

Further attempts will be made to develop such techniques to study the total molecular wavefunctions in its depth.

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R C Mehrotra

Starting his research career in 1944, Mehrotra can be credited with having established the first research school of synthetic metallo-organic (inorganic) chemistry in India. There are two unique characteristics of his achievements: (i) a number of research problems taken by him originated from searching questions of his students, and (ii) in spite of working in rather poorly equipped laboratories coupled with heavy administrative duties, the work of his research school has corrected numerous persisting mistakes in the literature and most of his rather speculative predictions on structural aspects of a large number of novel compounds have been verified by later workers who had access to more sophisticated facilities.

Author of about 600 original research papers and review articles and supervisor of about 100 research students, Mehrotra has contributed in a number of diverse fields like: (i) Adsorption indicators, (ii) Polymetaphosphates, (iii) Simple and bimetallic alkoxides of metals (main group transition and inner-transition), (iv) Metal-carboxylates, (v) Metal-β-diketonates, thio-β-diketonates, oximates, dialkyldithiophosphates, and (vi) Derivatives of organo-tin, -silicon, -germanium, -arsenic and -antimony. In all these fields, the work of his school has been followed up in numerous laboratories around the world and is profusely referred to in a large number of treatises, monographs and even textbooks. For example, his work has been considered to be of sufficient importance to be quoted in the *Annual Reports of the Progress of Chemistry* published by the Royal Society of Chemistry, UK, almost continuously since 1949.

An important achievement of Mehrotra during the early stage of his work was the preparation of aluminium tri-soaps[1]. These simple compounds were presumed to be non-existent after dozens of published unsuccessful attempts at their preparation, followed by review articles explaining the reasons for their non-existence. After some initial scepticism, the findings of Mehrotra were confirmed with the following words in the abstract of a research paper [*J chem Soc*, (1956) 1972]: 'Mehrotra's claim to have prepared aluminium tri-soaps is confirmed'. Mehrotra was specially invited to present this work at the sixteenth IUPAC Congress held in Paris in 1957.

For presenting his work on kinetics of the reaction between glucose and alkaline bromine[2], Mehrotra was invited to the 140th national meeting of the American Chemical Society held in Chicago in 1961.

His work[3] on the reaction of acetylacetone with titanium tetrachloride

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corrected the 50-year old notion about the trimeric nature of Ti(acac)$_2$Cl$_2$ which was described wrongly even in undergraduate textbooks in inorganic chemistry. Mehrotra presented this work at the seventeenth IUPAC Congress held in Munich in 1959 and in a special lecture at the Gordon Research Conference held in New Hampshire in 1961.

At an invitation from the Editor *Talanta*, Mehrotra contributed a review article on Adsorption indicators in precipitation titrations[4].

Mehrotra's reporting of the synthesis and properties of monoalkyltin (IV) trialkoxides[5] prompted Prof. A G Davies to write to him a personal letter mentioning his own failure to synthesize such derivatives.

Over the years, Mehrotra has been invited to deliver a series of special plenary lectures at various national and scientific gatherings, in which he reviewed his contributions in specific fields of his interest[6–15]. He has, in addition, published a number of books[16–23], which have received wide acclaim.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

K Nagarajan

Nagarajan's interests in the subject are broad-based and wide-ranging. These include medicinal chemistry, chemistry of plant protective agents, applications of multinuclear NMR spectroscopy, study of novel reactions and chemistry of natural products. Brief descriptions are given below of the contributions in each of these areas.

(1) Medicinal Chemistry

Nagarajan headed the medicinal chemistry division of CIBA-GEIGY Research Centre, Bombay, for over two decades. Several drugs emanated from among over 16000 compounds which were synthesized by him and his group and evaluated biologically. He was intimately associated with all the aspects of the development of these drugs—chemistry, biological efficacy and safety assessment, metabolism, galenical formulations and clinical trials. These contributions were mentioned in a plenary lecture and have been summarized in a review article[1]. Out of more than 2000 new chemical entities synthesized by Nagarajan and submitted for biological evaluation, the following three drugs have been developed and several potent leads discovered:

(i) *Nitroxazepine* (*Sintamil*$^{(R)}$), a novel dibenzoxazepine antidepressant[1,2] marketed in India and mentioned in the citation for the Bhatnagar Prize in Chemical Sciences awarded to Nagarajan for the year 1974.

(ii) *Satranidazole (Cibemid*$^{(R)}$), a potent nitroimidazole with a wide spectrum of antimicrobial activity useful in the treatment of amoebiasis, giardiasis, trichomoniasis and anaerobic bacteria[1,3,4]

(iii) *Tinazoline* (*Varsyl*$^{(R)}$), a vasoconstrictive indole derivative useful as a nasal decongestant[1].

Implantation inhibitors, antidiabetics, antibacterials, antituberculars, anthelmintics, anticonvulsants, CNS depressants[5] and antiinflammatory activities have also arisen out of this work[1].

(2) Plant Protective Agents

In his new position at the R & D Centre of Searle (India) Ltd, Bombay, in addition to sustaining his interest in the field of drugs, Nagarajan is involved with agrochemicals—process development, formulation and elaboration of new active compounds. The isolation of natural products with plant protective properties is gaining increasing importance globally for reasons of ecology and safety. Nagarajan plans to focus his attention on this emerging area.

(3) Heterocyclic Synthesis

A considerable part of the work in

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medicinal chemistry is concerned with the design of novel heterocyclic structures and a wide variety has been handled, especially condensed heterotricycles[6]. The use of acyl derivatives of cyclohexano-1,3-diones can be mentioned specially, since it has produced interesting chemistry and biological activity[7].

(4) Applications of NMR Spectroscopy

Nagarajan has used ^{1}H NMR spectroscopy extensively and successfully to solve several problems in organic chemistry—structures, including conformational and configurational details, e.g. of pyridophenanthridones[8] and reactivity, viz. of enamines[9]. Interest in this area has been extended to encompass ^{13}C (ref. 10), ^{15}N and ^{31}P spectroscopy also. Their effective use in solving intractable structural problems in heterocyclic chemistry has been reviewed[11] and will be pursued.

(5) Novel Reactions

Nagarajan's investigations during the last 35 years have uncovered many novel reactions whose mechanisms have been explored. The following are representative examples.

(i) Novel formation of 3-amino-4-oxo-4,5,6,7-tetrahydroindoles in the reaction of 2-phenacyl dimedones with hydrazines and of 5-amino-cinnolines in the Schmidt and Beckman rearrangements of 5-oxo-5,6,7,8-tetrahydrocinnoline derivatives[7].

(ii) Novel transformation of 1-benzyltetrahydroisoquinolines to benzoxazepinoisoquinolines[12].

(iii) Novel reaction of nitroimidazoles with diazomethane to form imidazopyrazoles[13].

(iv) Novel behaviour of 1-(2-nitrophenoxy)-naphthalene towards triethyl phosphite[14].

(6) Natural Products

Nagarajan's contributions to natural products chemistry have been wide-ranging and cover isolation, structure elucidation and synthesis.

(i) *Alkaloids* : Anistrocladine (naphthyl isoquinoline), kopsine (heptacyclic indole), tylophorine (phenanthraindolizidine). An abiding interest in the chemistry of isoquinoline alkaloids is evident in two review articles[15,16].

(ii) *Terpenes* : Ishwarone (tetracyclic sesquiterpene).

(iii) *Oxygen heterocycles* : Wedelolactone (a pterocarpan derivative).

(iv) *Carbohydrates, antibiotics* : Amicetin (nucleoside-petide antibiotic) and synthesis of aminosugar nucleosides.

(v) *Peptides* : Development of a novel peptide synthesis via hydroxamic acid esters formed from nitrile oxides.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

G K Narayana Reddy

Most of the work carried out in our laboratory is related to hydride, carbonyl and related complexes of platinum group metals. However, some work of significance has also been done on coordination by perchlorate ion as also on complexes of cobalt and nickel with substituted benzimidazoles.

A substantial portion of the investigations carried out in the earlier years was connected with the study of the nature of metal-hydrogen and metal-carbonyl bonds. As a part of this study, a number of hydride, carbonyl and hydridocarbonyl complexes of platinum group metals, especially rhodium and iridium stabilized by tertiary arsines, have been synthesized and their properties investigated. Several complexes related to the hydride and carbonyl complexes and relevant to the main theme of investigation have also been isolated. Thus, complexes of the types MHX_2L_3, $MX(CO)L_2$, $MHX_2(CO)L_2$, $MX_3(CO)L_2$ and MX_3L_3, where M is Rh or Ir; X is a halogen; and L is a tertiary arsine, have been isolated. Dioxygen complexes of iridium of the formula $IrX(CO)(O_2)L_2$ have also been made[1-3].

The ease with which the hydrido compounds take part in substitution reactions towards the introduction of nitrogen donor ligands like pyridine(py), 2,2′-bipy-ridyl(bipy), *o*-phenanthroline (phen) and similar ligands has been investigated. As a result of this study, new complexes of the types $[RhX_2L_2(N\text{-}N)]^+$, $[RhHXL_2(N\text{-}N)]^+$ and RhX_3L_2Q, where N-N is a bidentate chelating nitrogen heterocycle and Q is a monodentate nitrogen heterocycle, have been prepared[4].

These investigations have shown that the stability of the M-H bond and the ligand field strength of the H^- ligand are dependent on several factors, such as the charge on the metal atom, σ-donor capacity and π-acidity of the other ligands present in the complex. It has been shown that the way the τ_H values of the hydridic hydrogen vary in the simple halohydrides of rhodium and iridium (MHX_2L_3) can be used for structural assignment. The effect of solvent on the ν_{M-H} of the hydrido compounds has been investigated: this work could also be of diagnostic value in assigning structures to the hydrido compounds. A comparison of the ν_{CO} frequencies of the iridium-carbonyl complexes suggests that the effective oxidation state of the metal in these compounds increases in the order:

$$IrX(CO)L_2 < IrX(O_2)(CO)L_2 < IrHX_2(CO)L_2(H\ \textit{trans}\ \text{to}\ X) < IrX_3(CO)L_2 < IrHX_2(CO)L_2(H\ \textit{trans}\ \text{to}\ CO)^{2,3}.$$

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Another area investigated by our group is the relative coordinating ability of carbon monoxide and p-tolyl isocyanide (p-tNC) and the ease of formation of metal-carbonyl bond by palladium, platinum, ruthenium and osmium. As a part of these investigations, complexes of the types $[PtX(CO)L_2]^+$ and $[MC1(p\text{-}tNC)L_2]^+$, where M is palladium or platinum and L is tertiary phosphine or arsine, have been isolated[5,6]. Similarly, complexes of the types MX_2L_4, MX_3L_3, $[Ru_2X_3L_6]X$, $MX_2(CO)L_3$, $MX_2\ (CO)_2L_2$, $MHX(CO)L_3$, $[MH(CO)(N\text{-}N)L_2]^+$ and $[MX(CO)\ (N\text{-}N)L_2]^+$, where M is ruthenium or osmium, have also been isolated and characterized. Treatment of $RuX_2(CO)L_3$ and $MHX(CO)L_3$ (M = Ru, Os) complexes with p-tNC results in the displacement of one of the arsine ligands to afford $RuX_2(CO)(p\text{-}tNC)L_2$ and $MHX(CO)\ (P\text{-}tNC)L_2$ respectively. Investigations on the properties of these compounds have shown that the π-acceptor capacity of isocyanide gets reduced drastically in the presence of CO[7].

Our group was the first to isolate cationic carbonyl species of Rh of the formula $[Rh(CO)_2(N\text{-}N)]^+$, where N-N is bipy, phen, 2,2′-biquinoline(biq) or 2, α-pyridyl benzimidazole (pybzl). A number of related species of the types $[Rh(CO)_2L_3]^+$, $[Rh(CO)\ (N\text{-}N)L_2]^+$, $[Rh(CO)\ (N\text{-}N)L]^+$, $RhX(CO)_2(N\text{-}N)$, $[Rh(CO)QL_2]^+$ and $RhX_3(CO)\ (N\text{-}N)$ (where Q is pyridine or benzimidazole or a derivative of one of these and L is tertiary phosphine or arsine) have been isolated and factors responsible for stabilization of 5-coordination as against 4-coordination in these systems have been exmined. Some of these compounds are being investigated elsewhere for their catalytic activity[8,9].

Binuclear complexes of rhodium and iridium of the formulae (diene)MX-N-N-XM(diene) and $(CO)_2MX\text{-}N\text{-}N\text{-}XM(CO)_2$, where diene is 1,5-cyclooctadiene or norbornadiene and N-N is a bidentate non-chelating nitrogen heterocycle, have been isolated. Crystal structure analysis of (cod)(Cl)Rh-μ-pyrazine-Rh(Cl) (cod) confirms the bridging nature of pyrazine and similar ligands[10].

Investigations on metal-diene chemistry have been taken up recently. A convenient method for the isolation of the palladium cationic complex $[Pd(cotl)\ (cod)]ClO_4$, where cod is 1,5-cyclooctadiene and cotl is 1,3-π-cyclooctenyl unit, has been found. Several related compounds of the types $[PdX(cotl)]_2$, $[Pd(cotl)\ (N\text{-}N)]^+$ and $[Pd(cotl)L_2]^+$ have been isolated and their properties have been studied. It is found that π-cyclooctenyl unit is rather strongly bound to palladium and resists displacement[11].

Yet another area of our interest has been the investigation of the coordinating ability of perchlorate (generally a non-coordinating ion). In this connection, a number of complexes of the copper and zinc group metals stabilized by tertiary arsines and phosphines of the types ML_3ClO_4, ML_2ClO_4, $ML_3(ClO_4)_2$ and $ML_2(ClO_4)_2$ (where L is a tertiary arsine or phosphine ligand) have been synthesized. It is found that perchlorate is covalently bound to the metal in a large number of these complexes[12,13].

In the recent past, investigations have been initiated on the study of complexes of iron, cobalt and nickel with nitrogen heterocycles of biological interest, such as substituted imidazoles and benzimidazoles. These studies will be extended to other heavier transition metals[14].

Many of the transition metal complexes synthesized in these laboratories are potential catalysts for reactions involving organic substrates. During the last couple of years, several of these have been investigated for their possible catalytic activity towards hydrogenation under ambient conditions[15]. It has been found that some of these complexes, for instance, $RhHCl_2(Ph_2MeAs)_3$, $RhCl(CO)_2$-biq, [Rh(cod) (bipy)] (Rh(cod)Cl_2] and the binuclear complexes such as (cod)RhX-N-N-XRh(cod), are efficient catalysts for the hydrogenation of olefinic double bond and reduction of keto and nitro groups.

A few of the complexes of rhodium with nitrogen heterocycles as ligands have been found to activate CO towards its reaction with molecular oxygen and NO under homogeneous conditions. These studies will be continued and the possibility of using these catalysts for the water gas-shift reaction will be examined. Efforts are being initiated towards the use of some of the above cited complexes, especially those containing nitrogen heterocycles, as calalysts in the study of reactions involving the use of synthetic gas under conditions of high pressure and temperature.

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D Nasipuri

(A) Synthetic Organic Chemistry

(1) *Biogenetic-type Synthesis of Diterpenoids and Related Compounds*

In addition to synthesizing a large number of degradation products derived from naturally occurring diterpenes, a novel method for the synthesis of podocarpa-8,11,13-triene system[1,2], the skeletal structure of the tricyclic diterpenes has been accomplished. The method, which is based on the concept of biomimetic synthesis, consists in acid-catalysed cyclization of (6E)-9-aryl-2,6-dimethyl-nona-2,6-dienes or their equivalents. The mechanism of the reaction, however, has turned out to be a non-concerted one proceeding through a 1,3,3-trimethyl-2-aryl-ethylcyclohexyl cation followed by cyclialkylation with the aromatic ring leading to a mixture of *trans*- and *cis*-podocarpatrienes. The mixture, however, undergoes oxidation to a *trans*-7-oxo- and a *cis*-6,7-dioxo-derivatives, which separate easily on column chromatography. The method has been employed for the synthesis of a number of diterpenoids, e.g. methyl ethers of nimbiol, sugiol, xanthoperol and some related compounds.

Later, the above dienes were converted into mono-epoxides (terminal) and used for biomimetic synthesis of 3-oxygenated diterpenoids (e.g. hinokiol) and furanosesquiterpenes (e.g. pallescensin A) stereoselectively[3]. A few rearranged products from the carbocation intermediates have also been isolated and their formation explained.

(2) *Synthesis of Polynuclear Aromatic Hydrocarbons*

During 1950's, a few general methods for the synthesis of important polynuclear aromatic hydrocarbons, e.g. phenanthrene, chrysene, indenophenanthrenes, picene[4], etc. have been developed. In many cases, they supplement the known literature methods and their merit lies in their versatility and simplicity.

(3) *A Hydrochrysene Approach to Steroid Synthesis*

Starting from 6-methoxy-2-acetonaphthone, a simple synthesis of 1,11-dioxo- and 1-oxo-octahydro-8-methoxychrysenes has been achieved[5]. The method consists in the condensation of the Mannich base of the above acetonaphthone with ethyl β-oxoadipate giving the product in one step, which contains rings A, B and D (homo) of the steroid nucleus with an acetic acid side chain suitable for the building up of ring C.

A few heterocyclic steroids, e.g. mono-aza- and di-aza-steroids (one containing a β-lactam ring) have been synthesized[6].

(4) *Synthesis of Other Natural Products*

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An approach was made (1961) towards the total synthesis of the anti-tumour alkaloid, colchicine. Although this work could not be completed here, it was followed up by a group of French workers to achieve a convenient entry into this very important group of alkaloids.

Dihydropsoralidin and isopsoralidin (furocoumarins) have been synthesized[7], confirming the structure of psoralidin, isolated by an Indian group of workers.

Other syntheses include those of pharmacologically important tricyclic benzazepins, miltirone (a diterpenoid quinone[8]), a number of polynuclear hydrocarbons containing thiophene ring and many other heterocyclic systems.

(5) Two organic syntheses, namely, those of ethyl β-oxopimelate and *trans*-4-*t*-butylcyclohexanol have been published in *Organic Syntheses, Coll Vol. 5.*

(B) Mechanistic Organic Chemistry

(1) The mechanism of reduction of benzenoid compounds with metal-amine-proton donors (Birch reduction) has been finalized jointly with Prof. A J Birch[9].

(2) The formation of cyclohexenone derivatives by Robinson-Mannich base reaction, a synthetically useful method, has been studied in detail[10].

(3) The 1,3-cyclo-addition reactions of diazoalkanes with 2-methoxymethylene cyclic ketones have been studied with interesting results.

(4) Recently, a single electron transfer mechanism for the reduction of cyclic ketones with alkoxyaluminium dichlorides has been proved from stereochemical data[11].

(5) Hagemann's ester (ethyl 2-methyl-4-oxocyclohex-2-en-1-carboxylate), a potentially useful synthetic intermediate, has for the first time been shown to alkylate at both C-1 and C-3[12].

(6) A convenient procedure for Michael reaction using phase transfer catalysts has been developed; it is particularly suitable for unstable substrates.

(C) Stereochemistry of Carbon Compounds

(1) *New Stereoselective Reducing Agents*

One of the most significant contributions in organic stereochemistry from Nasipuri's laboratory is the development of a few stereoselective reducing reagents, particularly bornan-2-exoyloxyaluminium dichloride, which reduce cyclohexanones and other cyclic ketones predominantly to the less stable axial alcohols ($> 90\%$). The reagents are easy to prepare and offer a convenient synthesis of the less stable diastereoisomers (alcohols) exclusively[13].

(2) *Enantioselective Reduction of Prochiral Ketones and Aldehydes*

The above reagents may be derived from cheap natural products, such as (+)-camphor, (−)-menthol, and (−)-borneol, all available in 100% optically pure form. These are found to be very good enantioselective hydride transferring reagents and have been employed for the preparation of chiral alcohols of high optical purity from a large variety of ketones and aldehydes. A transition state model for these reductions has been suggested, which is widely accepted by other workers. An overview of the work has been published recently[14].

(3) *Stereochemistry of Michael Addition to Ethyl Cyclohexylidenecyanoacetate*

In an attempt to ascertain the contributions of the controversial 'product development control' (PDC) on the stereochemistry of reduction of cyclohexanones[13], the addition of a few nucleophiles to a number of ethyl cyclohexylidenecyanoacetates has been studied. The results show that in spite of the high conformational requirement of cyanoacetate side chain, equatorial attack predominates, a fact which weakens the participation of PDC in such reactions.

(4) *Dynamic Nuclear Magnetic Resonace and Energy Barrier around Some Crowded Single Bonds*

The energy barriers to conformational inversion of a number of 3-arylcyclohexenones around aryl-cyclohexenone bond and of 1-aryl-4,4,6-trimethyl-2-thioxo-1,2,3,4-tetrahydropyrimidines around aryl-nitrogen bond have been determined by the use of dynamic nuclear magnetic resonance technique. The results have been correlated with the steric and electronic effects of the substituents[15].

(5) *Determination of Configuration*

The configuration of the two diastereoisomeric 1-carboxy-4-methylcyclohexane-1-acetic acids has been established[16] unequivocally by ^{1}H-NMR and ^{13}C-NMR.

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H L Nigam

The early second half of this century saw a renaissance in inorganic chemistry. As a young worker initiated into transition metal chemistry research, I was naturally drawn to it and I have pursued this field for the last three decades. I have made significant contributions to the nature of metal-ligand bond in general and to fundamental probes in coordination compounds like oxidation state of the central metal ion, coordination number and stereochemistry in particular, using mainly magnetic and spectral (UV, visible IR, NMR, ESR, Mössbauer, X-ray absorption) and polarographic techniques. I have done pioneering work in India on the application of X-ray absorption spectroscopy to coordination compounds. These researches have settled some issues and opened up fresh avenues of investigation in India and abroad. The highlights of such contributions made singly and jointly are briefly mentioned below.

Bond Structure in Metal Carbonyls[1–3]

In the wake of exciting developments in the study of metal-carbon bond and heightening interest in the theory of π-bonding due to the work of J Chatt, R S Nyholm, G Wilkinson and E O Fischer, the bond structure in metal carbonyls and substituted complexes was reviewed[2]. In the course of work on metal carbonyls using *o*-phenylene bis-dimethyl di-tertiary arsine as a ligand, we, for the first time, established Fe(I) and Mo(II) and reported a seven-coordinate Mo(II) complex. The first tetra-substituted hexa-carbonyls of group IV were also synthesized and characterized.

Metal-Sulphur Bond[4–6]

The donor-acceptor relationship of metal-sulphur (M-S) link based on electronegativi-ty and M-S $d\pi$-$p\pi$ or $d\pi$-$d\pi$ bonding does not conform to any uniform pattern. Efforts were, therefore, made to rationalize a lot of existing data and gather new information by synthesizing and characterizing new complexes involving a number of d^6, d^7, d^8, d^9 non-bonding electron configuration metal ions and some medium field mercaptide ligands like thiopropionic acid, thiomalic acid, thiosalicylic acid, thiolactic acid, thiovanol, etc. This led to the synthesis of a number of Ni(II) complexes exhibiting a novel type mixed stereochemistry (e.g. square planar-octahedral) in the same molecule[6]. Polarographic study of several of these ligands was made.

X-Ray Edge Absorption Spectroscopy as Applied to Coordination Compounds[7–9]

X-ray absorption spectroscopy, particularly using synchrotron radiation X-ray source, has in recent years emerged as a powerful technique for solving many

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intriguing problems of structural chemical importance even involving metal-dilute systems like metalloenzymes where other conventional methods fail to provide an unambiguous solution. The theoretical and experimental developments prior to synchrotron radiation were reviewed[8] for the first time. Very significant contributions have been made in this area. For recording K-absorption-edge-spectra (photographi-cally), a 40 cm radius Cauchois-type curved crystal spectrograph using mice as analyser has been employed. The technique has been exploited to furnish evidence for providing an unambiguous proof of mixed-valency in some copper complexes of biological interest. A correlation has been attempted between the optical spectra (10 Dq values) and X-ray absorption spectra (low energy absorption-edge-structure) of some cobalt complexes. A detailed investigation on a large number of copper complexes known to exhibit metal-metal-exchange interaction has led to proposals of the position of principal absorption maximum as a fundamental probe as against the hitherto accepted edge position. A novel correlation has been proposed between experimental edge-width and coordination stoichiometry, based on electronegativity of the metal and ligands in question. Our pioneering work in this field has triggered research activity in various laboratories in India, UK, USA and USSR.

Studies on Metal-Metal Exchange Interaction[10,11]

In solid state such compounds were studied using X-ray absorption-edge spectrometry and a diagnostic criterion was evolved.

The solution electrode behaviour of some Cu(II) alkanoates known to exhibit metal-metal exchange interaction to varying degrees was studied in various organo-aqueous solutions at e.m.e. (polarographi-cally).

Correlation of Spectral and Redox Properties of Coordination Compounds[12-13]

Studies on electro-reduction of complexes of copper containing dipyridyl/phenanthroline and some amino acids as mixed ligands at d.m.e. led to the correlation that the half-wave potential-shifts towards more negative side relate to the ligand-field band-shifts. A possible electron transfer mechanism on the basis of orientation of orbitals towards the electrode on the line proposed by Vlcek was put forward. π-Acid effect on the electrode behaviour of these ternary complexes in solution gave very interesting results.

Activation of Small Molecules by Transition Metal Complexes[14,15]

The chemistry of activation of small molecules by transition metal complexes has assumed enormous importance over the years for various reasons: (i) The role of O_2 in biological reactions, (ii) the role of C_XO_Y, N_XO_Y, S_XO_Y as atmospheric pollutants, and (iii) inadequate information on N_xS_y, $C_xO_yS_Z$ and similar compounds.

We published the first ever review[14] on the chemistry of thio nitrosyl (NS) and its transition metal complexes. We have also published a review[15] on the chemistry of COS and its interaction with transition metals.

Future Plan of Work

(1) Interest will be continued in X-ray absorption spectroscopy and its application particularly to biologically

important compounds. There is no facility in India yet for work on synchrotron radiation X-ray absorption spectroscopy and there is urgent need to create such a facility. In the meanwhile, work is proposed to be done through collaboration with scientist friends in UK and USA.

(2) Another area of interest will be sulphur-ligands, in particular the activation of small molecules by transition metal complexes in the context of studies on air pollution and its control.

(3) Work is also proposed to be done on the conversion of solar energy into storable chemical energy.

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Nitya Anand

Drug design is the basic foundation of the search for new biologically active substances. This does not imply that drugs can be totally designed, but the use of rationalized approaches and methodologies for the development of new drugs, whether through total innovation or through lead optimization, can reduce the number of structures to be studied to arrive at the optimal therapeutic properties. The major thrust has been to contribute to the development of this science of drug design, and to use this knowledge to search for new drugs, particularly for fertility regulation, tropical infectious diseases and the central nervous system.

While different approaches to the design of lead molecules and prototypes have been employed, one specific concept which has led to a considerable degree of success is that of molecules which present the required pharmacophores and functionalities in a fixed geometry[1]. In the case of molecules which can have a number of possible conformations or rotameric forms, only certain discrete conformations may be responsible for the specific response. Information about these "active" conformations can be obtained by synthesizing analogues which would "freeze" these conformations by incorporating them in a rigid or semi-rigid structure with limited conformational mobility. If these rigid analogues do show the desired biological activity, such an approach would not only provide drugs with "selective" action but would also offer a deeper insight into the topography of the receptors involved in their action and a better understanding of the phenomenon of recognition and of transduction of messages in biological systems, which lie at the core of an understanding of such systems.

In an approach to the design of post-coital contraceptives based on interference with some of the peripheral events in reproduction in the female, the hormonal events during the pre-implantation and early implantation phases of reproduction seemed to be vulnerable targets. And among the agents which appeared most suitable for such interference, were non-steroidal estrogens, some of which had already been shown to be differentiable from "frank" estrogens by their weak estrogenic and in some cases even anti-estrogenic activity, and could be considered as "atypical" estrogens. And yet the activity of most of these compounds is mediated through a common receptor system, the estrogen receptor. A study of the binding contribution of the critical molecular components of such compounds also appeared to provide an approach to an understanding of the structural correlates

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of estrogenic action, and a basis for the development of "atypical" estrogens which would interfere with estrogen-dependent post-coital or early implantation phases of reproduction.

Triarylethylenes and ethanes are known for their modified estrogenic responses; the former can exist in two geometrical forms, while the latter, due to the possibility of rotation around the C_1-C_2 bond of the ethane moiety, can assume several conformations, one of which may have optimal receptor binding. Since there is no way of directly visualizing the ligand receptor complex as yet, it is difficult to know this conformation. Incorporation of the ethane or ethylene moiety into a cyclic system would restrict the rotational freedom, and would thus limit the number of geometric isomers or conformations that the substituents across the bond can assume. Based on these considerations, a variety of ligands which include variously substituted 2,3-diphenylbenzofurans, 3,4-diphenylcoumarins, chromenes and chromans, 2,3,4-triphenylfurans and some related compounds have been synthesized and studied for their receptor binding affinity with immature rat uterine cytosol receptors, uterotrophic activity in rats and anti-implantation activity in rats, dogs and monkeys. These studies indicate that the estrogen receptor binding site is possibly a composite of five sub-sites which are implicated in the binding of the complementary sub-structures of the different estrogen prototypes[2]. Based on their substructural characteristics and the presumed differences in receptor binding orientation, a new system of classification of estrogens has been proposed[2,3]. On the basis of these studies, *trans*-2,2-dimethyl-3-phenyl-4-p- (β-pyrrolidinoethoxyphenyl)-7-methoxychroman (Centchroman), in view of its weak estrogenic and strong anti-estrogenic action, high LD_{50} and significant anti-implantation activity, has been picked up as a candidate molecule for development as a post-coital antifertility agent[4], and is now under extended clinical trial as a weekly pill. It has also been found to be of value in estrogen-dependent advanced breast cancer cases[5].

N-phenylpiperazine, γ-benzoylpropyl and tryptamine are common pharmacophores present in a number of agents acting on the cardiovascular and central nervous systems. Molecules have been designed which incorporate these pharmacophores in different fixed geometrical presentations; one of these molecules, 2-γ (*p*-fluorobenzoyl) propyl-1,2,3,4,6,7,12,12 a-octahydropyrazino (2, 1-6, 1) pyrido (3,4-b) indole (Centbutindole) has emerged as a promising neuroleptic drug[6] with enantiomeric selectivity for the *laevo* isomer[7]. As these compounds have powerful dopaminergic antagonist activity, their activity provides some insight into the stereoselectivity of dopaminergic receptors.

Using a similar rationale, rigid molecules have been designed in a number of other areas: 1-aminomethyl-5,6-dihydroxyisochroman as a dopamine agonist[8], 3-methyl-8-ethyl-3,6,8-triazabicyclo (4,4,0) decan-7-one as an antifilarial agent[9] and 3-substituted 2,3,4,4a,5,6-hexahydro-1(H)-pyrazino(1,2-a) quinolines as antihypertensive agents[10].

Thus, studies with conformationally restricted analogues have been helpful not only in developing new biodynamic agents and drugs but also in mapping out the topography of the receptor site and in understanding ligand-receptor interactions at the molecular level.

Medicinal chemistry is now entering a new era with the availability of computer aids for QSAR studies, molecular graphics and X-ray crystallography for the study of the structure of receptors and receptor-ligand interaction and with the possibility of cloning receptor genes which would make receptor proteins available in larger quantities for physicochemical and molecular interaction studies. This will now result in greater inter-disciplinary weaving together of bio-organic chemistry, molecular biology and pharmacology and make drug design more rational and precise. Medicinal chemistry continues to offer exciting possibilities.

Development of New Immunomodulators

Immune response is the interface between health and disease, between chemotherapy and immunoprophylaxis, and, therefore, its regulation is most germane to rational treatment of disease. With the recent characterization of the structure of the minimal bacterial component responsible for immunostimulation as muramyldipeptide (MDP) or a trehalose dimycolate, it has become possible to study immunoregulation at the molecular and cellular levels, and immunomodulators have become amenable to SAR studies. Some novel hydrophilic derivatives of MDP and trehalose have been prepared which have shown interesting immunoadjuvant, immunostimulant and interferonsynergistic activities[11]. Such agents would not only be a *sine qua non* for the development of a new generation of genetically engineered or synthetic vaccines, but would also be the pro-host drugs of the future.

Organic Synthesis

Organic synthesis has special relevance for medicinal chemistry not only for synthesizing in a stereoselective manner the designed/conceived prototype, but also for developing high-yield, short-path synthetic methods with flexibility for obtaining homologues and analogues easily in large quantities required for screening and biological evaluation. With this purpose in view, the use of reactive intermediates which provide a large synthon, such as lactam acetals[12] and lactim ethers[13] and of Lewis acid-catalysed Diels-Alder reaction[14] for regio- and stereoselective synthesis, has been explored for the synthesis of heterocycles.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S C Pakrashi

Pakrashi started his research career with structural investigations on the indole alkaloids of *Rauwolfia* and related Apocyanaceae species which earned him international reputation. Since then he has made major contributions through studies on the constituents of various Indian medicinal plants in all their chemical and physical aspects which include isolation and purification of minor constituents, structure elucidation using modern physico-chemical methods, total syntheses of many of the active constituents, and structure-activity relationship. Some of his achievements are highlighted in the following paragraphs.

(1) Discovery of a new source of emetine, the well-known antiamoebic drug, and related alkaloids in *Alangium lamarckii* Thw. (Alangiaceae), an abundant indigenous plant and the only source of these drugs other than the exotic plant *Ipecacuanha* (Rubiaceae).

Alangium lamarckii was also shown to elaborate the pyridobenzoquinolizidines, a new class of alkaloids, and bharatamine, the unique protoberberine base conceivably derived by an unusual biosynthetic route. Recently, alamaridine, representing a new type of pyridobenzoquinolizidines, has been synthesized through a unique enamine cyclisation procedure using acyl chlorides.

(2) Isolation and structure determination of new types of steroidal alkaloids with a pyridine ring or with the unusual 22βH configuration, and of the first naturally occurring 22βO spirostane derivative from various *Solanum* species.

(3) Isolation from *Aristolochia indica* and structure elucidation of a new class of sesquiterpenes and of other interesting constituents possessing potent antifertility activity.

(4) Extraction from *Glycosmis arborea* and structure elucidation of arborinol, a representative member of a new type of triterpene.

(5) Complete structure determination of new germacranolides besides diterpenes and steroids from *Enhydra fluctuants* Lour, an edible marshy plant having high folic acid activity.

(6) Convenient and simple synthesis of quebrachamine (a potent hypotensive agent) and rhazidine (a potent antiarrythmic agent), the complex indole alkaloids.

A key intermediate for the synthesis of ajmalicine, an indole alkaloid in clinical use, has been prepared in a simple way in high yield.

(7) Total synthesis of vincatine, an oxindole alkaloid with seco-aspidosperma

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skeleton, and establishment of its structure and absolute stereochemistry.

(8) Development of a commercially feasible process for the conversion of quinine to quinidine, an antiarrythmic drug, which can ensure economic viability of the cinchona plantations.

(9) Studies on intriguing oxidation and reduction of quinazolinones and the mechanisms thereof.

Future Directions of Research

Besides continuing the current research activities, investigation on marine natural products, synthesis of deoxyoligonucleotides and study of drug-DNA interactions will be undertaken.

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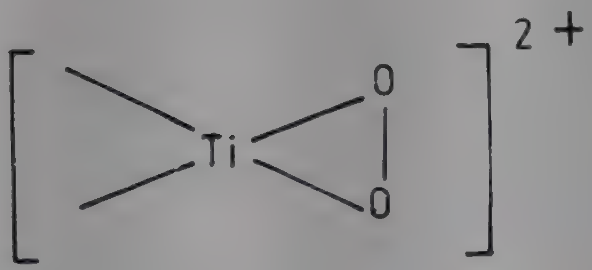
C C Patel

Some Representative Contributions in Coordination Chemistry

Sulphato, oxalato, malonato and maleato complexes of oxovanadium (VO^{2+}) and peroxotitanium (TiO_2^{2+}) were studied and structures assigned. A ligand series[1] was proposed from VO^{2+} IR stretching frequency shift, which corresponds to the relative stability of its complexes. The peroxo group in TiO_2^{2+} complexes like $TiO_2.C_2O_4.2H_2O$ was assigned the strained triangular ring[2] structure.



The thermal stability of the peroxo ring was shown to depend on the stability of the carboxylato group *trans* to the peroxo group[3].

The X-ray powder data and molecular structures of titanyl, zirconyl, vanadyl, thorium and uranyl perchlorates were determined[4,5]. Their complexes formed by neutral monodentate ligands like dimethyl sulphoxide, DMSO, quinoline-N-oxide, QNO, etc., were characterized.

The coordination behaviour of halide ions in the presence of QNO to di- and trivalent manganese, iron and cobalt has been investigated systematically[6]. In M^{2+} and M^{3+}, Cl^- is coordinated to M^{2+} and M^{3+}, I^- is generally coordinated to M^{2+} and non-coordinated in M^{3+} complexes. Bromide produces 1 : 1 electrolyte $[M(QNO)_6]$ $[MBr_4]$, where M represents Mn^{2+} and Fe^{2+}, but not Co^{2+}, which forms the pseudotetrahedral complex $[Co(QNO)_2Br_2]$. Fe^{3+} produces the 1 : 1 electrolyte $[Fe(QNO)_4\,Br_2]$ $[FeBr_4]$. Similar studies were carried out with other neutral monodentate ligands, but the complexes formed were not strictly identical.

Ferrous fumarate, $(FeC_4H_2O_4)_n$, is an excellent food additive to combat iron deficiency in humans. But it was not well investigated. Its preparation, physico-chemical properties, probable structure and nature of the unit cell have been described[7].

Some interesting copper (I and II) complexes were produced during our investigations. Pentakisantipyrine copper (II) perchlorate complex, $[Cu(Apy)_5]$ $(ClO_4)_2$, was assigned a square pyramidal structure[8]. Dimeric copper (II) complexes of levulinic and arylcarboxylic acids were prepared and characterized[9]. Stabilization and characterization of N, N-dibenzylidine-O-phenylinediamine complex of copper (I)

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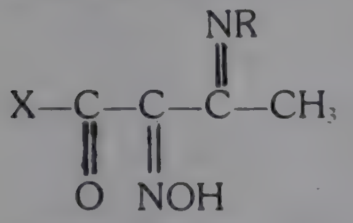
perchlorate was reported[10]. The benzimidazole complex of copper (II) iodide was also stabilized[11].

Jahn Teller distortion in manganese (III) complexes of neutral monodentate ligands was demonstrated[12].

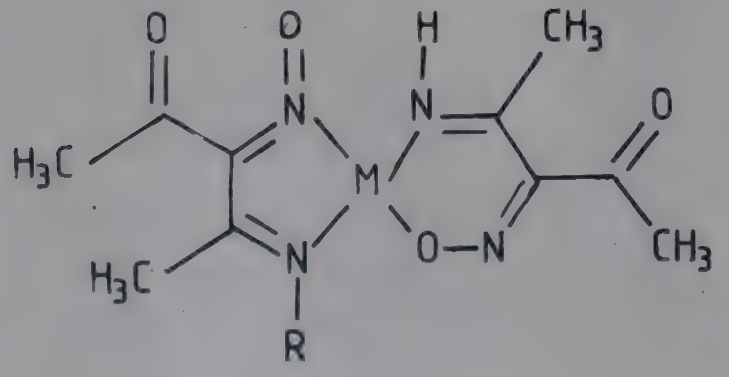
Coordination Chemistry of Isonitoso-β-ketoimines of Some Transition Metal(II) Ions

Metal(II) complexes of isonitroso-β-ketoimines,



$$\underset{\underset{\text{O}}{\|}}{\text{X—C}}\text{—}\underset{\underset{\text{NOH}}{\|}}{\text{C}}\text{—}\overset{\overset{\text{NR}}{\|}}{\text{C}}\text{—CH}_3$$ (HIAI)

where R = H, alkyl, etc., and X = CH_3, OCH_3, C_6H_5, etc., have been reported by several workers since 1926, but the correct structure was obtained independently in 1970 by Bose and colleagues[13] and Lacey *et al.* [Lacey M J, Macdonald C G, Shanon J S & Collins P J, *Aust J Chem*, **23** (1970) 2279]. All these authors proposed structure (**1**) for its Ni (II) complex



(1)

M = Ni^{2+}, R = H or alkyl group
M = Pd^{2+}, R = H.

in which one of the ligands is coordinated through isonitrosonitrogen and imino nitrogen forming 5-membered ring structure of IAI, while the other ligand coordinates through isonitroso oxygen and imino-nitrogen of IAI′, producing six-membered ring structure, the complex having the structure Ni(IAI) (IAI′). Since then we have synthesized and characterized several complexes of Ni(II), Cu(II) and Pd(II) of bidentate and tetradentate isonitroso-β-ketoimine ligands[14]. The same ligand (HIAI) produces asymmetric complex with Pd^{2+}, Pd(IAI) (IAI′), while R-IAI forms $Pd(R\text{-}IAI)_2$, a symmetric structure with only PdN_4 coordination. Cu^{2+} forms Cu(Me-IAI) (IAI′) and $Cu(Me\text{-}IAI)_2$.

Novel examples of unidentate coordination of isonitroso-β-diketones were observed when bis (isonitroso-β-diketonato) palladium(II) complexes were reacted with π-acids[15]. One of the isonitroso-β-diketones was coordinated to Pd(II) unidentately by nitrogen of isonitroso group only and the vacant position created was occupied by a π-acid, TPP, TPA, etc.

Bis (isonitrosomethylacetoacetateimino) palladium (II), $Pd(IMAI)_2$ and $Pd(IEAI)_2$ were synthesized and found to have symmetric structure with PdN_4 coordination. Thermal treatment of these complexes under reduced pressure transforms one of their bondings from isonitroso nitrogen to isonitroso oxygen, producing intramolecular chelate linkage isomer with PdN_3O bonding[16].

Phenylisocyanation and nitrosation reactions of some Schiff base complexes of diacetoxy boron were investigated[17].

Phenylisocyanate addition at γ-CH of thio-β-diketonates of some transition metals(II) was also studied[18].

A rare example of inter-ligand chelate linkage isomerism was obtained[19]. A variety of reactions of coordinated isonitroso-β-ketoimines were studied and a large volume of new data obtained.

Studies were carried out on some transition metal ions and some coordination compounds as enzyme models for fungal hydroxylase and penicillin acylase[20].

Electronic Structures and Properties of Some Biologically Important Hetero-aromatic N-Oxides

Correlation of the biological activity of some bio-molecules with their physico-chemical properties and consequently their electronic structure (structure-activity correlation) is a problem of fundamental importance in quantum biochemistry. The electronic structures of a series of 4-substituted pyridine N-oxides[21]; diazine mono- and di-N-oxides[22]; antibiotic molecules amimycin, aspergillic acid and pulcheriminic acid; N-oxides of the purine bases adenine, guanine and xanthine; the carcinogenic and mutagenic compound 4-nitroquinoline 1-oxide together with its analogue; and the antibiotic molecules iodinin and myxin were investigated using PPP, IEH, CNDO/2 and MINDO/2 MO methods. Their electronic spectra, dipole moments, photoelectron spectra, PMR chemical shifts, charge distribution, etc., were discussed in relation to their chemical and biological activities[23].

Thiocarbonyl Compounds and Their Applications in the Flotation of Sulphide Minerals

The behaviour of adsorbed xanthates[24,25] at the surfaces of sulphide minerals in aqueous media in the presence of air, oxygen, carbon dioxide and their binary mixtures were studied, as such information can be expected to be technically important for froth flotation of minerals. In some minerals, the use of air and oxygen promoted the adsorption of xanthates; in some, the xanthate film was oxidized to dixanthogen and got bonded firmly, and in others it was desorbed. Thus, differential behaviour of the adsorbed film provided a clue for selective flotation of minerals. It was, therefore, possible to selectively float chalcopyrite[26] from iron pyrite. Similar studies were carried out with dithiocarbamates[27,28] and they seem to be more efficient collectors.

Infrared[29] and electronic[30] absorption spectra of xanthic, dithiocarbonic and trithiocarbonic acids were studied. Infrared spectral assignments were made through normal coordinate analysis[31]. Methods of analyses were developed for the estimation of xanthates, dixanthogens, dithiocarbamates and thiuram sulphides.

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R C Paul

After partition of India, the Chemistry Department of the Punjab University was housed in the Delhi University Campus during 1947-49 and then shifted to Government College, Hoshiarpur, originally an intermediate college. In 1954, with practically no special equipment, research work in the field of non-aqueous solvents was started by Paul, which led to the establishment of a school on non-aqueous solvents. In the first few years, solvent properties of acetylchloride[1], acetylbromide and benzoyl chloride were looked into. The investigations involved quantitative determination of the solubilities of organic and inorganic solutes, study of the formation of solvates, solvolytic reactions, acid-base neutralization reactions, conductometric and visual titrations, infrared spectral studies on the solvates and determination of heats of solution of acids and bases in the solvents. This was followed by investigations on solvents, such as ethyl acetate, formamide, dimethyl formamide[2], acetamide[3], acetic anhydride, dimethyl sulphoxide, nitrobenzene, nitromethane, ethylformate, acetic acid, formic acid, sulphur monochloride, sulphur dichloride, phosphoryl bromide, thiophosphoryl chloride, sulphuryl chloride, thionyl bromide, nitrylchloride, triethylphosphate, tri-*n*-butylphosphate, and imidobis (sulphuryl chloride). Many of these halide and oxyhalide solvents were found to be excellent media for the preparation of anhydrous metal halides by the solvolysis of several metal salts.

Acetic acid[4] proved to be a good solvent for visual, conductometric and potentiometric titrations for quantitative determinations. Studies in formic acid indicated it to be a better ionizing solvent than acetic acid. Formates of Sn(IV), Ti(IV), Sr(IV), Th(IV), Cr(III), Fe(III), Al(III), Sb(V) and Si(IV) were synthesized and characterized, the last one for the first time. Imido bis (sulphuryl chloride) was shown to be a good protonic solvent and the pseudo-halogen character of the $N(SO_2Cl)_2$ anion was confirmed by the synthesis of novel derivatives of imido bis(sulphuryl chloride).

Among the highly acidic solvents studied were disulphuric, fluorosulphuric[5], chlorosulphuric and methane sulphuric acid[6]. Disulphuric acid was found to be an excellent medium for the formation and stabilization of polyatomic cations[7] (Te_2^{2+}, Te_4^{2+}, Se_4^{2+}, S_4^{2+} S_8^{2+}, P_8^{2+}, P_4^{2+} I_2^+, I_3^+, etc.) and monopositive and dipositive carbonium ions. The behaviour of halides, carboxylic acids, esters, ketones, alcohols, organic and inorganic acid halides and metal halides in disulphuric acid[8] was examined by cryoscopic, conductometric and spectral techniques. Such studies were found to afford a simple method for classifying organic acid halides and

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inorganic halides and oxyhalides into ionizable and non-ionizable compounds. The behaviour of several inorganic and organic solvents was also examined in fluorosulphuric[9] and chlorosulphuric acids. The formation and stability of polyatomic cations in these acids were, however, found to be dependent on the presence of a strong oxidising agent. Transition metal salts solvolysed in methanesulphuric acid to yield metal methanesulphates, which were found to be polymeric solids having octahedral arrangement of oxygen atoms around metal ions.

The physical properties of amide solvents were found to be highly suitable for the study of ion-ion and ion-solvent interactions. From conductance, thermochemical and cryoscopic studies on solutions of several electrolytes in formamide, N-methyl formamide, NN'-dimethyl-formamide[10], N-methyl acetamide, NN'-dimethyl acetamide, hexamethyl phosphotriamide and tetramethyl urea, limiting transference numbers, ionic mobilities, effective ionic radii and solvation numbers of various ions in solution were determined.

In the field of coordination chemistry, complexes formed by transition metal salts with ethyl picolinate, methyl picolinate, isopropyl picolinate, ethyl nicotinate and ethyl isonicotinate were studied. Stable uranium (V) chloride[11] complexes with nitrogen and oxygen donor ligands were synthesized and characterized. Anhydrous V(III), Cr(III), Mn(II), Cu(II), Co(II), Ni(II) chlorides were found to react with triethylphosphate to give diethoxyphosphato complexes with the formula $M[O_2P(C_2H_5O)_2]_n$, where $n = 3$ for M = V, Cr and $n = 2$ for M = Mn, Cu, Co and Ni. The behaviour of bis (dialkoxyphosphato) complexes of Co(II) and Ni(II) and bis (di, *n*-butoxyphosphato) complexes of Co(II) and Ni(II) and bis-(di, *n*-butoxyphosphato) complex of Co(II) as acceptors was also examined.

Coordination compounds of trichlorotin (IV), trichlorotitanium (IV) tetrachloroantimony (V) alkoxides with the general formula $SnCl_3(OR)$, $TiCl_3(OR)$ and $SbCl_4(OR)$; where $R = CH_3$, C_2H_5, n-C_3H_7, C_2H_4Cl, $C_2H_2F_3$, and $C_2H_2Cl_3$, with uni- and bidentate ligands containing oxygen and nitrogen donor atoms were studied. Quite different work carried out about the same time was concerned with the synthesis and study of the properties of complexes of benzanthrone, anthrone, nitroanthrone, benzilanthrone and methylanthrone with Sb(V), Sn(IV), Si(IV), Ti(IV), Ti(III), Bi(III), Fe(III), B(III) and Al(III) halides. Other coordination compounds investigated included those formed by benzoin, Schiff bases, bis (trialkyltin) oxide, aminobutoxysilenes and thiotrithiazyl bromide with metal halides. Some compounds of iron (III) with tertiary and secondary bases and with bidentate ligands were also studied.

Several addition compounds of Lewis acids with amides, hydrazides, ketones, aldehydes and organic carbonates and of acetyl chloride, benzoyl chloride, nitrosyl chloride, thionyl chloride, sulphuryl chloride, phosphoryl halides, sulphur monochloride, phosphorus halides and zirconyl chloride with amides and organic tertiary amines were isolated and characterized by infrared spectral studies.

Sulphur trioxide[12] was shown to form addition compounds with mono- and dicarboxylic acids, esters, boron and silicon alkoxides and inorganic bases. With nitrogen pentoxide, tetroxide and trioxide, it formed many adducts. Infrared spectral studies on $N_2O_5.3SO_3$ and $N_2O_5.4SO_3$ indicated them to be ionic having structures $(2NO_2^+)$ $(S_2O_{10}^{2-})$ and $(2\ NO_2^+)$ $(S_4O_{13}^{2-})$. Sulphur trioxide was found to react with iodine trichloride to form ICl_2 SO_3Cl and $I(SO_3Cl)_3$. Selenium trioxide was found to form addition compounds with organic nitrogen bases, inorganic acid anhydrides and with mono- and dicarboxylic acids.

Investigations on the syntheses of metal carboxylates led to the preparation of uranium (IV) acetate[14] by the reduction of uranyl chloride or uranyl acetate with zinc amalgam in acetic acid and from it uranium (IV) propionate, isobutyrate, isovalerate, caproate and benzoate were prepared by the acid interchange method. Similarly, carboxylates of Th(IV), La(III), Ce(III), Pr(III), Nd(III) and Sn(III) were also prepared by the acid interchange method. Zirconium(IV) carboxylates were prepared by reaction of $ZrCl_4$ with the corresponding acids.

Preparation of metal derivatives of dimethylformamide by solvolytic reactions in dimethylformamide was the first report on the existence of a new series of compounds named 'dimethylformamidyls'. Alkali metal dimethylformamidyls were isolated by reacting alkali metals with dimethylformamide below 0°C under controlled conditions. Dimethylformamidyl substituted Se(IV), Te(IV), Zr(IV), Al(III), Fe(III), Sb(III) and Bi(III) chlorides were prepared by metathetical reactions between metal halides and dimethylformamidyl sodium. New methods were also suggested for the syntheses of several organotellurium and organoselenium compounds, anhydrous chlorides and bromides of La(III), Ce(III), Pr(III), Nd(III), Sn(III), iron (III) acetate and chromylfluorosulphate.

My earliest researches in analytical chemistry involved the use of alkaline potassium permanganate, chloramine B, potassium metaperiodate and sodium chlorite as volumetric reagents. During investigations on nonaqueous solvents, I found crystal violet, benzanthrone and malachite green to be good reversible internal indicators for the determination of Lewis acids and bases in acetyl chloride and benzoyl chloride. Crystal violet, thymol blue, dimethyl yellow, methyl orange, methyl red and neutral red were found to be suitable reversible indicators in ethylacetate for the determination of organic bases with fluorosulphuric, perchloric and *p*-toluene sulphonic acids as titrants. The role of crystal violet and benzanthrone as indicators in phosphoryl chloride, arsenic (III) chloride, thionyl chloride and sulphuryl chloride was also investigated.

Fluorisulphuric acid[15], which is a very strong acid in acetic acid, was used extensively as an acidic titrant in acetic acid medium for the determination of organic tertiary bases, acetates, amino acids and alkoxides. The end point could be determined conductometrically, potentiometrically or with the aid of visual indicators. Acetone, alcohols or alcoholic mixtures could as well be used in place of acetic acid as solvents for some of the determinations.

Iodine and bromine cyanides were developed as oxidants for the quantitative determination of iodine, sulphite, thiosulphate, thiocyanate, arsenic (III), tin (II), mercury (I), iron (II), ascorbic acid, β-naphthol, hydrazine and its derivatives, thiourea and its derivatives, dithiocarbamates, xanthates, phenols and mercaptans, in aqueous and non-aqueous media by visual, conductometric and potentiometric titrations. Mercaptans were also determined titrimetrically using potassium hexacyanoferrate (III), chloramine-T and potassium persulphate as oxidants.

The work on dimethylformamidyl and other amidyls will be continued. The process gives organometallic compounds in a very simple way and has lot of potential for further exploitation.

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S Rajappa

Innovation has been recognized as an absolutely essential ingredient in all aspects of synthetic organic chemistry, including drug research. In the following account, an attempt has been made to trace the development of ideas that have led to the discovery of fruitful new reactions during the past 20 years in my research career. It is hardly necessary to point out that the development of new concepts in one area has led smoothly to progress in several overlapping fields. Thus, enduring interest in the reactivity of enamines and iminoethers has resulted in a rich haul of research output in such diverse areas as peptides, heterocyclic synthesis, push-pull ethylenes and NMR spectroscopy.

Peptides

Cyclodipeptide monoiminoethers were synthesized for the first time and shown to be useful synthons. When these are reacted with anthranilic acid, tri- and tetracyclic quinazolones result. In these products, a dramatic preference for the alkyl substituent in the pyrazine ring to occupy the axial position has been demonstrated. In the tricyclic quinazolones, where conformational flexibility is available, that conformation in which the alkyl occupies the axial position is preferred even at elevated temperatures, whereas in the rigid tetracyclic quinazolones, a remote proline centre is forced to epimerise in order to accommodate the alkyl group in an axial position[1,2].

New reagents have been developed for peptide-bond formation; aromatic and aliphatic nitrile oxides have been shown to react with N-protected amino acids to form active esters, by addition followed by rearrangement[3].

Cyclization of linear peptides under mild hydrogenolytic conditions has been achieved. The necessary prerequisite for this—an active ester stable to hydrogenolytic conditions—was provided by the Woodward-Kemp reagent[4].

Heterocycles from Iminoethers and Enamines

Iminoethers possess both an electrophilic and a nucleophilic centre. They can, therefore, act as bifunctional synthons for the construction of heterocycles by reaction with molecules possessing complementary nucleophilic-electrophilic centres. This idea was initially utilized in the reaction of cyclodipeptide monoiminoethers with anthranilic acid. The subsequent use of acetone dicarboxylic ester as the complementary reactant with iminoethers has led to a simple one-step synthesis of pyridones[5].

The attempt to prepare thiazepine derivatives from enamines resulted in a

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serendipitous synthesis of multifunctional thiophene derivatives. Enamines form adducts with isothiocyanates, and these adducts on condensation with an α-haloketone, form thiophenes in good yields. If instead of enamines, amidines or iminoethers are the substrates in the above reaction, novel 5-acyl thiazoles result[6].

Push-Pull Ethylenes

Nitroenamines: If the carbon nucleophile derived from nitromethane reacts with iminoethers, the product is a 1-amino-2-nitroethene, a nitroenamine. The term "nitroenamine" includes both 1-amino-2-nitroethenes and 1,1-diamino-2-nitroethenes. Are nitroenamines true enamines, or are they "push-pull" ethylenes? Several unexpected reactions have been discovered which clearly point towards the 'push-pull' nature of these molecules[7]. Some fascinating fragmentations have been encountered in this area[7,8].

Can nitroenamines be put to synthetic use? Two examples are provided below. A variety of nitroheterocycles have been synthesized using open-chain nitroenamines as precursors[9]. Such a general approach offers two specific advantages over nitration of a preformed heterocycle: Emergence of novel substitution patterns and retention of vulnerable substituents.

The second synthetic use of nitroenamines was discovered by chance. Catalytic reduction of nitroenamines derived from lactams under acid conditions gave symmetrical bis-aminoalkylpyrazines by a process of cyclodimerization[7].

The work on nitroenamines led to interest in other push-pull systems. The objective of synthesizing 1,1-diamino-2-thioacylethenes was realized through a novel C-thioacylation of amidines by a Willgerodt-Kindler reaction[10].

NMR Spectroscopy

Correlations have been arrived at between chemical shifts and nucleophilic reactivity in a series of enamines from a study of ^{1}H and ^{13}C NMR spectra. Such correlations are useful in predicting the reactivity of enamines. A particularly intriguing paradox was the discovery of the magnetic non-equivalence of the methyl groups in the poorly enaminic substance, 1-dimethylamino-2-nitroethene. This has been explained as being due to the ground-state contribution of push-pull structures[7].

The 2-nitromethylidene thiazolidine system has proved to be a puzzle; unexpected solvent-dependent E/Z isomerism has been encountered in this case. Possible explanations have been offered for this phenomenon as well as for the downfield shift of the methine proton in the Z species[11].

Other New Synthetic Procedures

The retro-ene reaction has been used in a novel ecologically acceptable route to isothiocyanates. This depends on the pyrolysis of an acylthiourea; the thiocarbonyl group is ultimately derived from inorganic thiocyanate[12].

Quinone-imines

The idea of using quinone-imine derivatives as transient intermediates for the synthesis of heterocycles is currently engaging our attention. This would involve an intramolecular nucleophilic attack on the quinone-imine generated *in situ*. This has already led to viable routes to hitherto inaccessible benzthiazoles and benzimidazoles[13,14]

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

L Ramachandra Row

The major contributions of Row during 1950-1980 fall under five heads: (A) Flavonoids and other polyphenolics, (B) Lignans, (C) Alkaloids, (D) Triterpenoids, and (E) Physalins. Several heartwoods and medicinal plants from the local forests of Andhra Pradesh, comprising about 150 species were examined. New compounds were isolated and structures established on the basis of extensive chemical and spectral studies. These studies revealed several structures of considerable complexity and enabled further examination of their reactivity and synthesis.

(A) Flavonoids and Other Polyphenolics

Rotenoids are powerful plant insecticides, but are harmless to higher animals. Furanoflavones are closely related to them. From *Pongamia pinnata* Linn.[1], three new furanoflavones, pongapin, pinnatin and gammatin, were isolated, their structures established and confirmed by synthesis.

Several synthetic analogues, such as furanoflavones, furanoisoflavones and furanobenzochromenes, were synthesized and their piscicidal activity[2] studied, which revealed toxophoric nature of the pyrone moiety in these compounds. They are expected to form a class of potential, harmless synthetic insecticides.

Semicarpus anacardium Linn.[3] (dhoby nut) is claimed to be a powerful drug for rheumatism and even for cancer in Ayurvedic medicine. Our study revealed several catechol derivatives with long side chains of C-9 to C-15. The defatted shells contained biflavonoids and their glycosides. Similarly, from the defatted shells of *Anacardium occidentale* Linn., biflavonoids were isolated and their structures established.

During the study of the heartwoods and barks, the ellagi- and gallo-tannis were examined and 4-methoxy-3′,4′-methylenedioxy ellagic acid from *Crataeva nurvala* Buch. and 3,4,3′-tri-O-methyl flavellagic acid from *Terminalia paniculata* Roth. were isolated.

(B) Lignans

Our interest in this field started with the identification of the crystalline components as lignans from the bitter liver drug, *Phyllanthus niruri* Linn.[4]. Two of them, phyllanthin and niranthin, are intensely bitter and belong to the category of butyrolignans; the remaining three non-bitter lignans, hypophyllanthin, nirtetralin and philtetralin, belong to the class of 1-phenyl tetralins. The plant contains some more lignans and work on them is being pursued in these laboratories.

Lignans were also isolated from the poisonous plant, *Cleistanthus collinus*

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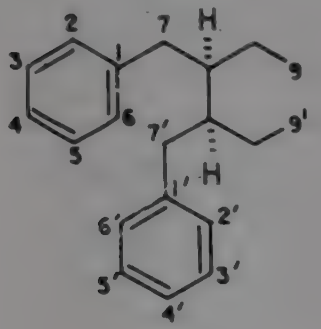
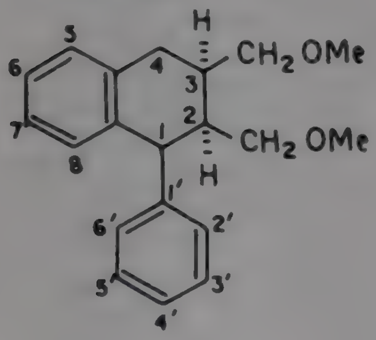
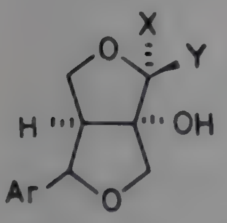
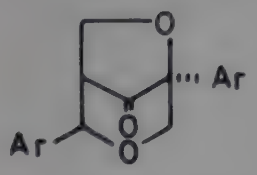
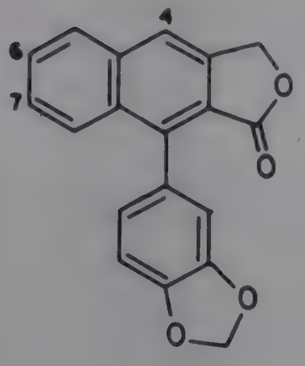
Roxb.[5], and also from the commercial timber (heartwood) of *Gmelina arborea* Linn.[6]. All these lignans are new and their structures were established beyond doubt and in a few cases their synthesis was achieved (Table 1).

Table 1—Lignans

S.No.	Lignan type	Compound	Substituent			Source
			OMe	O-CH₂-O	OH	
1.	*Butyrolignans*					
	 2 7 H 1 3 9 4 6 7′ 9′ 5 1′ H 6′ 2′ 5′ 3′ 4′	(1) Phyllanthin	3,4,3′ 4′,9,9′	—	—	*Ph. niruri*
		(2) Niranthin	5,3′,4′ 9,9′	3,4	—	—do—
		(3) Dihydrocubebin	—	3,4 3′,4′	9,9′	*Cl. collinus*
2.	*1-Phenyltetralins*					
	 H 5 4 CH₂ OMe 6 3 2 CH₂ OMe 7 8 1 H 1′ 6′ 2′ 5′ 3′ 4′	(4) Nirtetralin	8,3′,4′	6,7	—	*Ph. niruri*
		(5) Philtetralin	7,8,3′,4′	—	—	—do—
		(6) Hypophyllanthin*	6,3′,4′	7,8	—	—do—
3.	*Furofurans*					
			X	Y		
		(7) Arboreol	OH	Ar		*Gmelina arborea*
		(8) Isoarboreol	Ar	OH		
		(9) O-Methyl arboreol	OMe	Ar		
		(10) O-Ethyl arboreol	OEt	Ar		
	(Ar = piperonyl)	(11) 6″-Bromo isoarboreo	Ar	OH		
		(12) Gummadiol	Ar	H,4 OH		
		(13) Wodeshiol	Ar	H,5 OH		*Cl. collinus*
		(14) Gmelanone	—	—		*Gmelina arborea*
	(Ar = piperonyl)					

*Revised structure, cf Ganeshpuri P A, Schneider G E & Stevenson R, *Tetrahedron Lett* (1981) 393.

4. *1-Phenyl naphthalene lactones* from *Cleistanthus collinus* Roxb.



	at 6,7	at 4
(15) 3,4-Dihydro-taiwanin-C	O-CH$_2$-O	H
(16) Taiwanin-E-glycoside	O-CH$_2$-O	-O-(β 3,4-di-O-methyl xylopyranosyl)
(17) Cleistanthin-D	OMe, OMe	-O-[(β 2,3,5-tri-O-methyl xylofuranosyl)]
(18) Cleistanthin-E	OMe, OMe	-O-[(β 2,3,5-tri-O-methyl xylofuranosyl-2,3 di-O-methylxylo furanosyl)1→4-O-βD-gluco pyranosyl)]
(19) Diphyllin diglycoside	OMe, OMe	-O-[(β 2,3-di-O-methyl xylopyranosyl)1→4-O-βD-gluco pyranosyl)]

Of the several furofurans from the heartwood of *Gmelina arborea* Linn.[6], gmelanone is a rearranged product from arboreol. A biomimetic synthesis of gmelanone was also achieved in our laboratories, confirming the structure. This heartwood is also unique in the fact that it contained the unusual ethyl ether of arboreol and also the first ever bromine containing lignan, 6″-bromo-isoarboreol.

Among the notable syntheses of lignans, a stereospecific synthesis of phyllanthin was achieved, besides those of several 1-phenyl naphthalene lactones occurring in nature, for example, helioxanthin, taiwanin-C and justicidine-E.

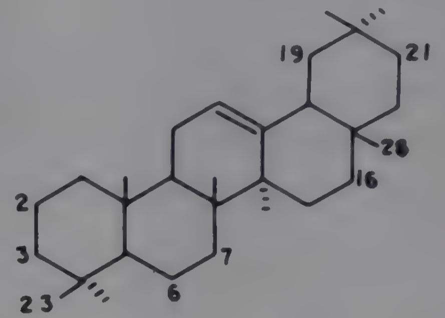
(C) **Alkaloids**

Two novel bisbenzyl isoquinoline alkaloids, tilliacorine and tiliarine, with a novel biphenyl link, were isolated from *Tilliacora racemosa* Colebr.[7]. Similarly, from the heartwood of *Adina cordifolia* Roxb.[8], two novel indole alkaloids, adifoline and cordifoline, were isolated and the structures proposed. Further, the alkaloids of *Aristolochia bractata* Retz., *Gyrocarpus jacquini* and *Cocculus* species were also examined.

(D) **Triterpenes**

Systematic chemical examination of the commercial timbers from Andhra Pradesh forests (Terminalia, Diospyros, *Albizzia*, *Gmelina*, *Swietenia*, etc.) was taken up. The forest produce from *Acacia* and *Sapindus* species was also included in this study. The medicinal plants of *Euphorbia* species were specially examined for their crystalline constituents from the latex and also from the whole plant. The new compounds, identified to be pentacyclic and tetracyclic triterpenes, are listed in Table 2.

Table 2—Triterpenes



S. No.	Name	Structure OH	 COOH	Source
(A)	*Pentacyclic triterpenes*			
1.	Tomentosic acid	2α, 3β, 19β 23	28	*T. tomentosa* W&A[9]
2.	Arjunic acid	2α, 3β, 19α	28	*T. arjuna* W&A[10]
3.	Arjunetin	D-glucose ester of the above acid		
4.	Tanginol	3β,6β.7β, 16β, 23,28		*B. acutangula*[11] Gaertn[11]
5.	Barringtonic acid	2α,3β,6β	23,28	—do—
6.	Acutangulic acid	2α,3β,18β	28	—do—
7.	Tangulic acid	2α,3β,18β	23,28	—do—
8.	Acacic acid	3β,16β,21β	28	*Acacia concinna* DC[12]
9.	Acacigenin	21β plant acid ester of the above acid		—do—
10.	Castonogenol	2β,3β,23,28		*Castenospermum australe* Cunn et Frans.
11.	Epi-multiflorenol	Olean-7-en-3α-ol		*Gelonium multiflorum* A. Juss.
12.	Epi-taraxerol	—		*Euphorbea royleana*
13.	Glut-5-en-3-ol	—		—do—
14.	Glut-5-en-3-one	—		*Eu. nerifloia*
(B)	*Tetracyclic terpenes*			
15.	Nerifoliol	3α hydroxy euphadiene		*Eu. nerifolia*
16.	Cycloswietenol	20-methylene-22-methyl cycloartane-3β-ol		*Swietenia mahagoni* Jacq[13]
17.	30-Norcyclo-swietenol	30-nor-20-methylene-22-methyl cycloartane-3β-ol		—do—

From the commercially important soapnuts, *Sapindus emarginatus* Vahl.[14] and *S. mukorossi* Gaertn.[14], two new saponins were isolated in pure condition and shown to have been derived from hederagenin. The pure saponins are quite stable and possess considerable commercial value.

Reactivity, rearrangement and interconversion: During the study of the triterpenes, known and new, the reactivity of the hydroxyls and arboxyl groups was examined carefully, so that their configuration and position in complex triterpene skeleton could be fixed unequivocally. It was observed that the 18β-hydroxyl of acutangulic and tangulic acids hindered the lactonisation of 28 carboxyl with 12-13 double bond. This configuration was also confirmed by ^{13}C NMR spectra of both acids. Again, the 19β-hydroxyl in tomentosic acid suffers ready elimination, while the 19α-hydroxyl in arjunic acid requires stringent conditions. The case of 16β-hydroxyl in acacic acid is more interesting; this acid is very unstable and suffers facile lactonization between 28 carboxyl and 21β-hydroxyl. This instability was not observed in the absence of 16β-hydroxyl or when this hydroxyl has α configuration. The stabilization of the lactone ring is supposed to be due to the strong hydrogen bonding of the 16β-hydroxyl with the carbonyl of the lactone ring, which is not feasible if it has α-configuration.

The lactone between the 28 carboxyl and 21β hydroxyl in acacic acid lactone may be expected to cause deep seated steric distortion in the skeleton. That this is true was revealed by the study of Wagner-Meerwein Rearrangement[15] of acacic acid lactone and its isomer, in which the ring A suffered the familiar contraction, but the double bond moved over to 5,6 position, clearly due to the preferential escape of the 6β axial hydrogen. This study was extended to several typical triterpenes like oleanolic acid, lupeol, bauerenol, taraxerol, etc. and very interesting structural effects were discovered.

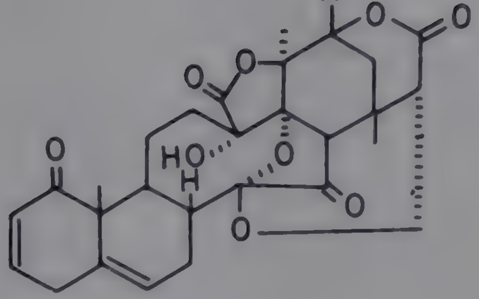
Further, the introduction of 2α-hydroxyl in 3β-hydroxyolean-12-ene skeleton was accomplished elegantly with lead tetra-acetate. Thus, stereo-specific synthesis of methyl arjunolate from methyl hederagenate and machaerinic acid from oleanolic acid was accomplished.

Normally, the 9-19 cyclopropane ring in cycloartenol opens up to give 10β methyl in the presence of protonic reagents. But it could be made to suffer a stereospecific cleavage to yield 9β-hydroxymethyl derivative, if the ring A in cycloarten-3-one[16] carried a double bond between 1 and 2 positions. Thus, a biomimetic introduction of 9β-hydroxymethyl was achieved by the above method, giving experimental support to the biogenetic origin of 9β-hydroxymethyl in cucurbitacins.

(E) Physalins

In 1969, Prof. T Matsura reported the isolation of three physalins, A, B, and C, from *Physalis alkakengi* Linn. They possess a complex ergostane skeleton with seven rings and contain more than 8 oxygen atoms. In view of their reported anti-tumour properties, three *Physalis* species[17] were secured through the Botany Department, Andhra University, and our studies added eight more new physalins, all structurally derived from physalin B.

Table 3—New Physalins



S. No.	Compound	Structure			Source
		en or	epoxy	OH	
1.	Physalin B				*P. angulata*
2.	Physalin D	—	—	5α, 6β	*P. angulata*
3.	Physalin E	—	—	5α, 7α	*P. angulata*, *P. lancifolia* and *P. pubescence*
4.	Physalin F	—	5α, 6β	—	*P. angulata* and *P. lancifolia*
5.	Physalin G	Δ^4	—	6β	*P. lancifolia*
6.	Physalin H	—	—	7β	*P. angulata*
7.	Physalin I	—	—	5α-OMe, 6β	*P. angulata*
8.	Physalin J	—	5α, 6α	—	*P. angulata* and *P. lancifolia*
9.	Physalin K	—	4α, 5α	6α	*P. angulata*
10.	Pubescenol	4α,7α-dihydroxy-1-oxo 24α, 25α-epoxy-2,3-dihydrowithanolide.			*P. pubescence*[18]
11.	Dehydropubescenol	4α,7α-dihydroxy-1-oxo-2-en-24α, 25α-epoxywithanolide.			*P. pubescence*[18]

Their structures were established by a study of their chemical reactions and spectral data.

The co-occurrence of the two withanolides in *P. pubescence*[18] seems to suggest a biogenetic relationship between physalins and the simpler withanolides. Compounds with intermediate structure, like withaphysalins and physapubescin, were reported from *Physalis* species. The simpler withanolides may, therefore, be considered as progenitors of the complex physatins.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M V Ramaniah

Ramaniah started research in nuclear and radiochemistry with PhD work on the 9.5-MeV deuteron fission of thorium at Washington University during 1953-56. Subsequently, he carried out investigations on 450-MeV proton fission of uranium at the University of Chicago during 1956-57. Research and development work in nuclear and radiochemistry was initiated at the Bhabha Atomic Research Centre in 1958 and has been pursued since then covering a wide spectrum of programmes. The major contributions of Ramaniah are in fission chemistry convering mass, charge and kinetic energy distribution and chemistry of actinides covering process chemistry, chemistry of plutonium fuels, pre- and post-irradiation examination and molten salt reactor chemistry.

1. Fission

1.1. *Neutron Induced Fission of Actinides*

Detailed investigations have been carried out at Trombay using radiochemical techniques on various aspects, such as mass, charge and kinetic energy distribution and angular momentum of fission fragments using recoil catcher techniques, radiochemical separations and high resolution gamma spectrometry. These investigations brought out the importance of (i) single particle aspects, such as the influence of the spherical/deformed nuclear shells and nucleon pairing, and (ii) collective aspects, such as the influence of fragment deformation, dynamics of the late stage of the fission process and the role played by the potential energy surface of the fissioning nucleus on fission systematics.

1.1.1 *Mass distribution* : Mass distribution studies have been carried out over a wide range of nuclei—^{227}Ac, ^{229}Th, ^{232}Th, ^{231}Pa, ^{232}U, ^{235}U, ^{237}Np, ^{239}Pu, ^{241}Pu and ^{245}Cm—and the results have led to an understanding of several important aspects. The transition from three-peaked distribution in the Ac-Th-U region to two-peaked distribution in the heavier actinides was explained in terms of two-mode hypothesis, i.e. different barrier heights for symmetric and asymmetric splits and a correlation was found between this difference and mass asymmetry. The results also showed stronger dependence of the symmetric component of the neutron number of the fissioning nucleus.

1.1.2 *Kinetic energy distribution* : Kinetic energy distribution in the fission of a number of nuclei—^{232}Th, ^{232}U, ^{233}U, ^{237}Np, ^{239}Pu, ^{241}Pu, ^{241}Am and ^{245}Cm—was studied using thin/thick target and integral range measurements. Recoil ranges were converted into kinetic energies, using range energy correlations. From the kinetic energy distributions, values of kinetic energy deficit were obtained. An

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interesting correlation was obtained underlining the importance of the double magic closed shell configuration (of 82 neutrons and 50 protons) for fission fragment mass around 132, which showed a linear decrease in kinetic energy deficit as the symmetric fragment mass approached 132, tending to zero or near zero kinetic energy deficit for the fission of ^{264}Fm; this was subsequently confirmed by the results of fission of fermium isotopes elsewhere. Using the experimental kinetic energy data, a simple method was developed to calculate fragment deformation and total excitation energy. Fragment deformations calculated by this method indicated that the symmetric split is governed by the liquid drop behaviour, while the asymmetric split is governed by the fragment single particle behaviour.

1.1.3 *Charge distribution* : Studies on charge distribution carried out in the thermal neutron fission of actinide nuclei (^{229}Th, ^{233}U, ^{239}Pu, ^{241}Pu and ^{245}Cm) and spontaneous fission of ^{252}Cf brought out the influence of deformed and spherical shells and of nucleon pairing in low energy fission through various parameters involved in isotopic/isobaric yield distribution profiles like the most probable mass/charge, corresponding width parameters and the extent of charge polarization. The experiments involved short duration neutron irradiations, fast target transport by pneumatic carrier and fast radiochemical separations—all required for investigating short-lived fission products. It was found that the charge distribution becomes narrow in the vicinity of shell closure configuration around mass 132 and the yields of even fission products are higher than those expected from normal distribution, indicating the effect of nucleon pairing. It was also found that the extent of charge polarization increases with increase in mass asymmetry in a given fissioning system in conformity with the liquid drop potential energy surface. Further, this variation increases with increasing fissionability parameter of the fissioning nucleus. These trends were explained as being due to the compact shape of the fissioning nucleus at the saddle point, resulting in longer time of descent and permitting the fissioning nucleus to polarize its charge adequately to achieve the minimum potential energy. Another interesting feature emerging from the studies on technitium isotope yields in various fissioning systems is the important role played by the deformed shells of 66 and 88 neutrons, confirming that the shell effects are strongly manifested when they are in phase with liquid drop energetics.

1.1.4 *Angular momentum of fission fragments* : Studies on angular momentum of fragments derived from independent yields of fission product isomers and a statistical model based analysis in various fissioning nuclei (^{234}U, ^{242}Pu and ^{252}Cf) have shown the influence of deformed shells of 38 protons and 66 and 88 neutrons and also of odd-even nature of the fission fragments on the scission configuration; specific fragment deformations were evaluated. It was found that profiles of angular momenta and elemental yields vary inversely with the fragment atomic number, indicating strong coupling between the collective degrees of freedom influencing the scission configuration and the corresponding potential energy surface.

2. Charged Particle Induced Fission of Actinides

2.1 *9.5-MeV Deuteron Fission of Thorium*

The mass distribution in the 9.5-MeV deuteron fission of thorium was investigated and the results analysed in terms of the peak to valley ratio; the excitation energy of the compound nucleus enabled the understanding that the compound nucleus is ^{234}Pa formed by the deuteron tunneling through the coulomb barrier and not ^{233}Th that can result from the (d,p) reaction.

2.2 *450-MeV Proton Fission of Uranium*

In high energy fission, thick target recoil properties of fission products were studied in the 450-MeV proton fission of uranium. These studies led to estimates of the average kinetic energy, the average cascade deposition energy and the average anisotropy of the fission products. It was seen that at low cascade deposition energies, perpendicular emission of fragments is favoured, while at high deposition energies, forward-backward emission is favoured.

The cascade deposition energy calculated (using Monte Carlo intranuclear cascade calculation) from the recoil results for the formation of a specific nuclide agreed with that obtained from an analysis of its excitation function within about 20%.

2.3 *Fission of Thorium by 30-40 MeV α-Particles*

With the commissioning of the variable energy cyclotron at Calcutta, work was initiated on the study of alpha particle (30-40 MeV) induced fission of ^{232}Th, particularly charge distribution, fragment angular momentum and mass resolved angular distribution of fission fragments. Charge distribution studies have shown that the isotopic width parameter increases with increase in excitation energy and the most probable mass approaches the one expected from unchanged charge distribution hypothesis. This trend was explained in terms of the influence of nuclear temperature on the mass/charge equilibration, and faster descent from saddle to scission point in medium energy fission. Investigations on fragment angular momentum in this energy region indicated the effect of excitation energy and angular momentum of the fissioning nucleus on the fragment angular momentum and that the mechanism involved in thermal fission for evolution of the fragment angular momentum has smaller influence at this energy.

These studies have contributed to a better understanding of the nuclear fission process, particularly concerning the late stage of the fission process and have brought out the relative importance of the fissioning nucleus, deformation energy surface, fragment nuclear structure and dynamic path of descent from the saddle to the scission point.

To summarize, radiochemical studies of fission carried out by Ramaniah during the last 25 years have contributed to a better understanding of this highly interesting and complex nuclear reaction. Extensive investigations on mass distribution have shown that the one-, two- and three-peaked mass distributions in low energy fission arise due to the relative contributions of the symmetric and asymmetric modes of fission, which, in turn, depend on the difference in the barrier heights for these modes. It has been further shown that this difference strongly depends on the neutron number than the proton number of the fissioning nucleus and further, the variation of this difference with mass number of the fissioning nucleus explains the observed variation in the peak-to-valley ratio with the fissioning nucleus. Results of kinetic energy distribution demonstrated the influence of the doubly magic shell at mass 132 on the total kinetic energy and kinetic energy distribution. The fragment deformation calculated from the kinetic energy data has clearly shown that the symmetric mode is largely governed by the liquid drop behaviour. Results of studies on charge distribution and fragment angular momentum brought out the influence of 66 and 88 neutron deformed shells and further showed their greater effectiveness when in phase with liquid drop energetics. It was also shown that the extent of variation of charge polarization with mass asymmetry depends on the fissionability parameter due to the influence of the saddle point shape and dynamics of descent. Angular momentum studies provided estimates of fragment deformation and showed that the odd Z fragments have high deformation due to the polarization of even Z core by the odd proton. Results of studies on medium energy fission have shown the influence of the saddle point properties on charge distribution and fragment angular momentum due to higher excitation energy and shorter time of descent. These studies have thus contributed to a better understanding of the nuclear fission process, particularly concerning the late stage of fission process and have brought out the importance of the deformation energy surface, spherical and deformed nuclear shells, nucleon pairing and the dynamics of descent past the second saddle point.

3. Chemistry of Actinides

3.1 *Process Chemistry*

Process chemistry of plutonium was studied in detail. These studies were started with the ion exchange, solvent extraction and redox behaviour of plutonium under purex process conditions and were extended to various aspects like the use of U(IV) as reductant in place of ferrous sulphamate. The results have been useful for reprocessing of irradiated fuel. Process chemistry of neptunium was also studied in detail and optimum conditions were established for the recovery of byproduct ^{237}Np in a reprocessing plant without interfering with the recovery of plutonium.

3.2 *Molten Salt Chemistry*

Chemical investigations were carried out on the molten salt reactor concept utilizing plutonium as start-up fuel. The results established that PuF_3 has sufficient solubility and stability in the LiF-BeF_2-ThF_4 matrix of compositions of interest, making it (PuF_3) a suitable start-up fuel for molten salt reactors of converter or breeder type. The solubility data were analysed and an empirical correlation between the solubility of PuF_3 and the salt composition was obtained to calculate the solubility of PuF_3 in other salt compositions of interest.

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A V Rama Rao

(I) Anti-tumour Antibiotics

(a) *Anthracyclines* : For the last few years, perhaps no family of chemotherapeutic agents has attracted such worldwide attention as the anthracycline antibiotics for the treatment of cancer. Chief among them are daunomycin (**1**) and adriamycin (**2**), which have shown remarkable effectiveness in combating a variety of human cancers. In particular, adriamycin possesses considerable clinical value because of its effectiveness in curing a number of solid tumours and is considered to be the most effective single agent among all anti-tumour agents presently in use. During the last decade, continued interest has been shown in the total synthesis of these antibiotics, including one of its analogues, 4-dimethoxy-daunomycin (**3**), which has now assumed considerable clinical importance, as it is found to be 8-10 times more active than daunomycin and adriamycin. As there is no possibility of obtaining this product by fermentation, Rama Rao's group has concentrated its efforts towards its total synthesis. Many schools in USA have been engaged intensively on the synthesis of the aglycones of the above three products (**1**–**3**) for the last one decade. Rama Rao's group at the National Chemical Laboratory, Pune, took up this problem in late 1979 and made significant contributions towards the total synthesis of 4-demethoxy-daunomycinone (**4**), 11-deoxydaunomycinone (**5**) and daunomycinone (**6**). Rama Rao's group has been the only group so far to be not only involved in the total synthesis of various aglycones, but also to have made significant contributions in achieving the synthesis of L-daunosamine starting from D-glucose as well as from D-glucosamine.

Various approaches have been reported for the synthesis of 4-demethoxydaunomycinone (**4**) starting from easily accessible intermediates. The main strategy in this work was to build tetracyclic system by AB + CD coupling making use of the key synthon, 2-acetyl-5, 8-dimethoxy-1,2,3,4-tetrahydro-2-naphthol (**7**), as the starting material for different unnatural anthracyclinones. Rama Roy's group evolved various approaches to the synthesis of **7** employing Diels-Alder reaction and Freidel-Crafts acylation[1,4] Finally, they have worked out a stereo convergent synthesis of **7** by an elegant approach taking advantage of Sharpless asymmetric epoxidation[5].

The new anthracycline antibiotics which have shown significant antitumour activity with less cardiotoxicity include 11-deoxydaunomycin and 11-deoxyadriamycin. Rama Rao's group achieved a general regio-specific synthesis of 11-deoxyanthracyclinones involving the Diels-Alder reaction[6] and also demonstrated the synthesis of 11-deoxydaunomycinone,

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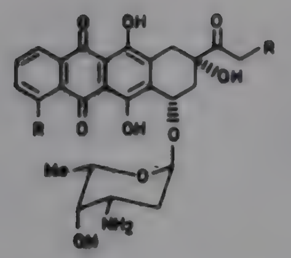
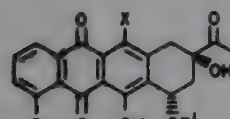
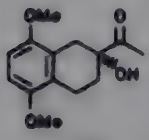


1 : R = OMe; R′ = H
2 : R = OMe; R′ = OH
3 : R = R′ = H



4 : R = OMe; X = OH; R′ = H
5 : R = OMe; X = R′ = H
6 : R = OMe; X = OH; R′ = H



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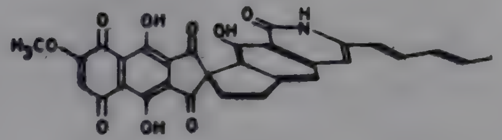

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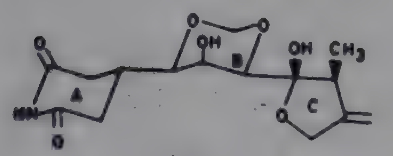


(9)

which can be adopted for large scale preparation[7,8].

Further work by this group has resulted in the synthesis of daunomycinone and 11-deoxydaunomycinone starting from a common synthon, 2-acetyl-5-hydroxy-8-bromo-1,2,3,4-tetrahydronaphthelene, which was made from *m*-cresol in eight steps[9].

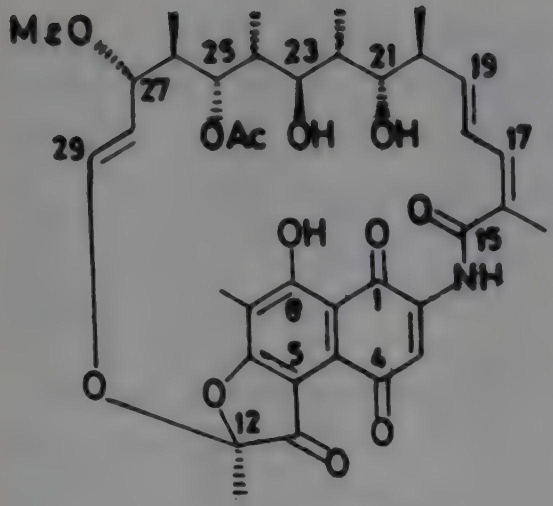
(b) *Fredericamycin A* : Fredericamycin A (**8**), an antitumour antibiotic produced by *Streptomyces griseus*, possesses an entirely novel spiro-[4,4]-nonane system, which has not been observed in any other types of antibiotics. It has certain interesting special characteristics, which may be important in determining its biological activity.

Rama Rao's group was the first to come out with a convenient approach to the building up of the spiro (4,4) nonane system present in **8**. This methodology is being made use of for the total synthesis[10] of **8**.

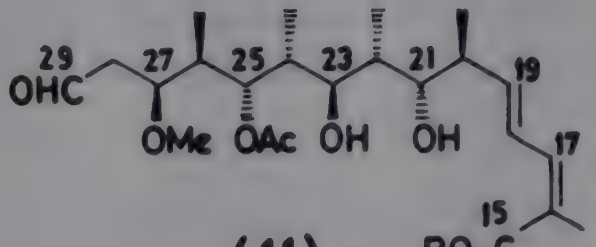
(c) *Sesbanimide A* : Sesbanimide A(**9**), isolated from the seeds of *Sesbania drummondii*, possesses potent antitumour activity. An efficient approach to the AB ring system of sesbanimide A starting from D-xylose and D-glucose to give the respective enantiomeric pairs has been worked out recently. The main problem in its total synthesis is to find a proper methodology for the construction of ring C. This was achieved by Rama Rao and his colleagues through an elegant approach[11].

(II) Synthesis of Macrolides

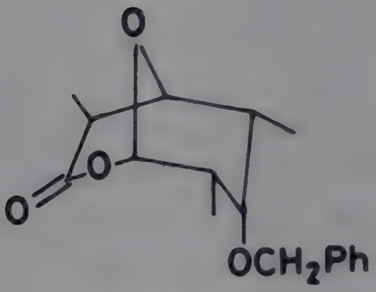
Rifamycin-S : Rifamycin-S (**10**), isolated from the fermentation medium of *Norcardia mediterrenei*, belongs to a novel class of antibiotics, ansamycins, which constitute an aliphatic bridge linking two non-adjacent positions of an aromatic nucleus. Rifampin, semisynthetic derivative of rifamycin-S, is marketed widely for the treatment of tuberculosis and leprosy. The first total synthesis of rifamycin-S has been reported by Kishi and his colleagues from Harvard University. Unlike the approach adopted by Kishi and others, wherein stereocontrol of the aliphatic chain has been achieved *via* acyclic intermediates for the synthesis of ansa chain (**11**), Rama


MeO
27
25
23
21
19
29
OAc
OH
OH
17
OH
O
O
15
NH
8
1
5
4
O
O
12
O
O

(10)


29
OHC
27
25
23
21
19
OMe
OAc
OH
OH
17
15
RO2C

(11)



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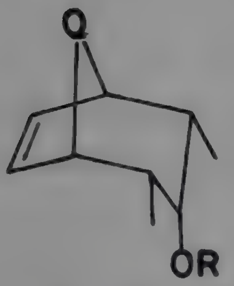
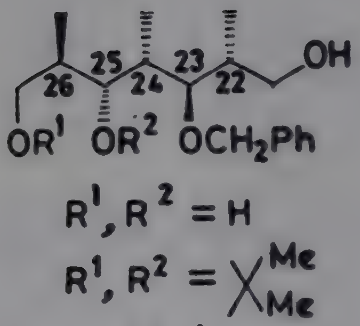


$R = H$
$R = CH_2Ph$

(12)


26
25
24
23
22
OH
OR1
OR2
OCH2Ph
R1, R2 = H
R1, R2 = Me Me

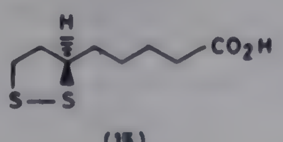
(14)

Rao and his group have made use of the acyclic intermediate (**12**) which has been made from furan. **12** was transformed to **13** by a simple and elegant methodology, which on exhaustive reduction with LAH gave the fragment **14** corresponding to carbon atoms C-21 to C-27 of the ansa chain[12]. Recently, they have worked out a stereospecific method for the fragment C-15 to C-21, which can be adopted for the total synthesis of ansa chain.

(III) Asymmetric-Synthesis of R(+)-α-Lipoic Acid

Lipoic acid (15), a protein-bound coenzyme of prosthetic group has been gaining increasing importance with many new physiological activities being attributed to it.

Rama Rao and his colleagues have explored three different approaches for the synthesis of R (+)-α-lipoic acid, viz. (i) from α-D-glucose, (ii) through Sharpless asymmetric epoxidation and (iii) through the use of 1,2R,4-butanetriol, a chiral synthon from R,R-tartaric aicd.



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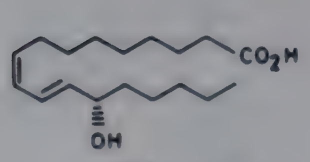
(IV) Stereoselective Synthesis of Hydroxy Unsaturated Octadecanoic Acids: The Self-defensive Substances in Rice Plant

Coriolic acid (**16**) and dimorphecolic acid (**17**), earlier isolated from bovine heart mitochondria, have been shown to possess unique calcium specific ionophoric activity. Recently, both these products, together with the other two hydroxy octadecatrienoic acids (**18, 19**), have been isolated from the resistant cultivar of rice plant (*Oryza sativa* L) and demonstrated to act as self-defensive substances against rice blast disease.

Rama Rao's group was the first to accomplish their synthesis through an elegant and simple approach[13].

(V) Plant Growth Regulators

(a) *l-Triacontanol* : In 1977, Ries and his colleagues at the Michigan State University demonstrated that l-triacontanol, an active constituent of alfalfa, increased plant growth and yield in several crop species [*Science*, **195** (1977) 1339]. As a fairly large quantity of 1-triacontanol is required for field trials to assess its importance as a plant growth regulator at a reasonable cost, Rama Rao's group aimed at achieving its synthesis by a method which can be amenable to multigram quantities, utilizing simple reactions and inexpensive reagents. They have followed two different approaches: (i) starting from stearic acid and making two successive additions of six carbon units through enamine intermediates[14], and (ii) making two successive alkylations of tosylmethylisocyanide followed by acid hydrolysis of the resulting product and reduction of the keto-ester to give 1-triacontanol[15].



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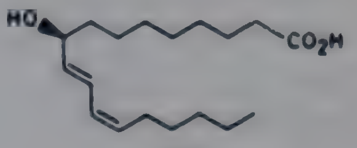

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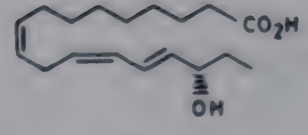

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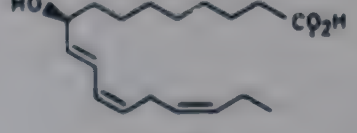

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(b) *Menadione sodium bisulphite, a promising plant growth regulator* : Rama Rao and his colleagues have demonstrated that menadione sodium bisulphite increases the growth of tomato plants and alfalfa callus and stimulates rooting of mungbean cuttings. Investigations into its effect on auxin metabolism resulted in decreased activity of the enzymes involved in IAA oxidation in tomato plants. The levels of IAA were increased by 3-4 fold following the application of menadione sodium bisulphite to tomato, cucumber, corn and capsicum plants[16].

(VI) Chemistry of Plant and Insect Pigments

Different species of *Garcinia* (F. Cruciferae) have been examined. Two isoprenylated benzophenone derivatives, camboginol and cambogin, have been isolated from the latex of *G cambogia*. The structure of camboginol and its conversion to cambogin, an enantiomer of isoxanthochymol, has been deduced[17].

Structures for albanol A and B, isolated from *Mours alba* bark, have been proposed an the basis of X-ray analysis of albanol A methyl ether. Albanol A and B are unique in many respects compared to other natural products isolated so far. Biogenetically, albanol A is derived by a 2 + 4 cycloaddition reaction between a chalcone and a C-prenyl-2-phenylbenzofuran followed by further transformations[18].

In close association with late Prof. K Venkatraman at NCL, Rama Rao has contributed significantly to the chemistry of various plant products with novel skeletons and to the chemistry of various insect pigments such as laccaic acids (lac dye), kermesic acid, etc.

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S Ranganathan

Chemical Simulation of the Art in Biosynthesis

The highly organized manner in which compounds of diverse complexity are synthesized in nature should represent the epitome of the art in organic synthesis, since these processes reflect millennia of experience and expertise in the aggrandization of molecular arrays. In sharp contrast, synthesis *in vitro*, barely a century old, stands out as a pale reflection. The successful delineation of pathways that would bring about the desired structural re-organization in resonance with nature, would not only have great practical charm, but also would enable the unravelling of latent and appealing facets of the art in biosynthesis. Our current endeavours, briefly outlined below, are in this direction.

A Centrally Controlled Approach to the Synthesis of Coded Amino Acids

In principle, innumerable α-amino acid structures are possible. Indeed, over 450 of these have been found in nature. Yet, only 20 α-amino acids are coded into the information system. A close scrutiny shows that in spite of their apparent side chain variation, a majority of them can be related to a single repeating unit, which can be called the alanyl synthon. Thus, appropriate attachment of residues to this synthon can generate as many as 15 of the 20 coded α-amino acids. Such an alanyl transfer synthon has now been prepared and the feasibility of a centrally controlled approach has been demonstrated with the synthesis of optically active phenyl alanine.

Coded α-Amino Acid $\longrightarrow$ Coded α-Amino Acid Change in Intact Peptides

A dramatic, although not too surprising, recent development arising from studies on oncogenes and their translation products and on the toxicity of proteins that incorporate non-coded α-amino acids is the finding that the replacement of even as little as one amino acid residue in a functional protein of any many as 100 amino acids could precipitate profound biological changes. We believe that it should be possible to bring about the replacement of one or more amino acid residues in proteins, at will, without affecting the peptide backbone, to other similarly coded ones. Such an expertise would have tremendous implications in protein research with respect to the study of an evolutionary profile for the genetic code, the preparation of proteins arising from translation of transformed genes, the preparation of critical analogues of very large proteins without facing the ardours of classical synthesis and in protein synthesis by restructuring. That such a strategy for protein restructuring is possible and feasible has been

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demonstrated by us with the transformation of the Ph-CH_2-side chain of phenyl alanine to HOOC-CH_2- of aspartic acid and the $(Me)_2CHCH_2$- of leucine in intact peptides, in good yields and with complete chiral retention.

Selective, Non-enzymatic, Chemically Mediated Cleavage of Proteins

It is now recognized that the synthesis of large proteins could best be brought about via semi-synthetic strategies. One of the promising methodologies is to cleave readily available proteins in a specific manner and then to restructure the fragments to provide the rare protein. This approach would be greatly facilitated by the development of strategies for the rupture of the protein backbone at specific sites. Work is in progress to selectively cleave proteins specifically at the carboxyl end, taking advantage of asparagine and glutamine side chains and to bring about the cleavage at the amino end by oxidative elimination of histidine, tryptophan and phenyl alanine side chains.

Selective Peptide Formation in Captive Environments

Selective peptide formation by condensation of ordered amino acids is a possibility that could have implications reaching back to the very origin of life. The ordering is planned to be effected by mixed crystals, microspheres, absorption on surfaces and in liquid crystal or micellar environments. The selectivity in the condensation leading to the peptide bond is envisaged via novel, tailor-made reagents that would have desirable properties, such as side chain recognition and polar selectivity.

Chemical Enhancement of the Stacking Property of Pyrimidine Codes

While the purine nucleotides can be stacked parallel, the pyrimidine bases do not show this intrinsic tendency. Because of this, a polypyrimidine nucleotide cannot be formed from a template of purine nucleotides, while the reverse is possible. One way to increase stacking properties is to introduce additional intrapyrimidine interactions, such as additional hydrogen bonds or additional charge transfer/hydrophobic interactions. Several suitable pyrimidines have been prepared and they are currently undergoing scrutiny using physical methods.

Chemical Simulation of Critical Cyclic Biological Processes

Several vital biological processes proceed by a cyclic pathway, as exemplified with the Calvin cycle, the pentose pathway, the Kreb's cycle, urea cycle and the ATP-imidazole cycle. They, above all, exemplify a highly refined and sophisticated art in organic synthesis and consequently their simulation would lead to significant advances in the area of structures. That such operations can be successfully simulated in the laboratory has been established by our group by studies on the ATP-imidazole cycle.

Novel and Practical Routes to Prostaglandins

Prostaglandins have therapeutic potential in the treatment of inflammation, control of blood pressure, bronchial function, atherosclerosis, heart attack, inhibition of blood clot formation, child birth, abortions, stomach ulcers and other related syndromes. Some prostaglandins have already passed clinical trials and have become available as drugs. Unlike most other biologically potent compounds, useful natural sources for prostaglandins are non-existent. Thus, chartering of viable synthetic routes to this class of hormones assumed great importance, since only by these procedures could prostaglandin therapy become economically feasible.

We discovered, during 1970-1977, two important routes to prostaglandins. In our first approach, popularly known as the nitroethylene route, the readily available cyclopentadiene is transformed to the "Corey lactone", which is then connected to all the prostaglandins. The overall pathway illustrates the use of nitroethylene as a powerful reagent and three unusual transformations that highlight application of theoretical concepts related to bond making and bond breaking to practical synthesis.

In the second approach to prostaglandins, we have restructured Indian castor oil to prostaglandin $F_1\alpha$, the primary prostaglandin, retaining as many as 17 carbons of the C-18 castor oil backbone. The C-18 methyl ricinoleate—the *trans*-esterification product of Indian castor oil—was thermally broken to C-11 and C-7 fragments, each of these restructured to specifications, employing new, aesthetically pleasing and practical strategies and then reunited via the medium of cyclopentadiene to create $PGF_1\alpha$. This feat, apart from providing a very practical entry to prostaglandins, illustrated a new facet in the art of organic synthesis, namely the transformation of abundantly available raw materials to rare products of need and in addition identified castor oil as a rich source for materials related to prostaglandin analogues, insect sex-pheromones and macrolide antibiotics. In a noteworthy demonstration of the latter facet, we have recently completed the restructuring of the C-11 and C-7 fragments to as many as 20 insect sex-pheromones.

Analysis of Non-occurring "Allowed" Reactions

We have named the many reactions, which though allowed according to the Woodward-Hoffmann rules in reality do not take place experimentally, as 'non-occurring allowed reactions'.

A detailed analysis of such reactions, using *inter alia* molecular orbital calculations and thermochemical data, have been made with particular emphasis on practical utility. A large number of experimental observations have been rationalized in a unified manner and several novel reaction types have been predicted to take place and some have indeed been realized experimentally.

In addition to the above, we have made studies in the area of reaction mechanisms, discovered new reaction types and have prepared "tailor-made" reagents.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S Rangaswami

The main contributions of Rangaswami have been in the area of chemistry of natural products. From the biological angle, they include the heart poisons and heart drugs, insecticides, cattle poisons, plant drugs used in the Ayurvedic and Siddha systems of Indian medicine and folk medicine, ferns and wood-rotting fungi.

Plants containing heart poisonous principles have been used by tribals for centuries for killing highly prized wild animals like lions, tigers, elephants and rhinoceros. Extracts of the plants were used under the name "arrow poisons" for poisoning the steel heads of arrows with which the animals were struck. The abuse of many such plants for suicidal and homicidal purposes is also known. The controlled use of extracts of some plants for the cure of heart ailments in men began around the end of the eighteenth century. These varied uses and abuses were all empirical, being based on chance observations followed by repeated confirmations. Today, we know the scientific basis of all these practices, thanks to the enormous progress in our knowledge of their chemistry and pharmacology.

"Cattle poisons" is a loose term used to signify a large number of plants whose only common feature is that they are poisonous to cattle, goats, sheep, horses and other domestic animals and are, therefore, dreaded by rural and tribal people. They belong to many plant families, genera and species, and their chemistry and pharmacology are equally varied.

No work had been recorded on the chemistry of Indian ferns prior to the work of Rangaswami. Wood-rotting fungi are very important in forest economy. Rangaswami was again the first to initiate chemical work on wood-rotting fungi in India.

Plants and their parts have been in use in India and South-East Asia in the Ayurvedic system of medicine since the days of Charaka and in the Siddha system since the days of the sage Agasthya. Chemical investigations by Rangaswami supported by pharmacological work have thrown light on the scientific basis of the use of these drugs and folk medicines.

From the chemical angle, the bulk of Rangaswami's studies have been in the area of steroids, terpenoids and glycosides.

Steroids

Steroids are grouped as sterols, bile acids, sex hormones, cortex hormones, cardiac genins, steroidal sapogenins and steroidal alkaloids. Cardiac drugs exert

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their specific action on the heart through their cardiac glycoside content. These glycosides on hydrolysis yield genins which are of two types and one or more sugars peculiar to this group. One group of cardiac genins, called cardenolides, have as side chain an $\alpha:\beta$-unsaturated γ-lactone ring called butenolide. The other group, called bufadienolides, have as side chain an $\alpha:\beta:\gamma:\delta$-di-unsaturated δ-lactone ring. All cardiac genins and glycosides are extremely sensitive and lose their cordiac activity in contact with even very weak alkalies. They are also unstable on treatment with strong acids and become inactive.

The bark of the Indian sweet scented red or white oleander (*Nerium odorum*) contains several glycosides built up of two genins, digitoxigenin and uzarigenin, and the sugars diginose, digitalose and glucose. Of all these, odoroside-B proved to be most important, since its genin provided the key to the understanding of the chemistry of many important glycosides. Uzarin, a glycoside isolated around the middle of the 19th century is built up on the genin uzarigenin which could not be isolated intact, because its linkage with sugars could not be broken, except under conditions detrimental to its isolation in intact form. But in odoroside B, the sugar diginose, because of its being a 2-deoxy sugar, could be hydrolysed under extremely mild conditions[1] by warming with $N/20$ acid for 20 min at 55-60°C. The genin odorigenin B proved identical with uzarigenin and its structure was established by standard procedures as a cardenolide isomeric with the earlier known digitoxigenin at position 5.

The seed kernels of *Thevetia neriifolia*, the yellow oleander ubiquitous all over India, are rich in fats (60-65%) and cardiac substances (up to 5%). The defatted powdered kernel was subjected to fermentation with the enzymes also present in the seeds, resulting in the breaking off of some of the surplus sugar units. The cardiac active mixture obtained subsequently was subjected to chromatography and yielded, besides the known neriifolin and cerberin, a new compound designated as peruvoside. It was chemically related to neriifolin as its aldehyde. Reduction of the aldehyde group to methyl yielded neriifolin itself[2], which is the α-L-thevetoside of digitoxigenin. The structure of peruvoside was thence deduced as the α-L-thevetoside of cannogenin, which is a very rare cardenolide. Great interest attaches to peruvoside, since it has pharmacological and clinical properties due to which it ranks with the three best standard drugs used universally in cardiac therapy, namely, digitoxin, digoxin and ouabain. In fact, it excels each one of these drugs in one respect or another.

The Indian squill *Scilla indica* has been shown to be rich in bufadienolide glycosides. A new bufadienolide isolated was scillarenin-bis-L-rhamnoside[3]. Glucose and digitoxose are the only sugars known to occur in repeat units and their glycoside is, therefore, unique in having two rhamnose units.

Among steroidal sapogenins, the most important is diosgenin, since it serves as the raw material for the manufacture of sex hormones and contraceptives. The Indian plants *Dioscorea prazeri* and *D. deltoidea* are very important in this respect. From the former four unique compounds designated as prazarigenins A-D have been isolated. They are all diosgenin derivatives and have a hydroxyl group at position 14. In addition, prazerigenin D has carbon 27 as a COOH, which is rather unique[4,5].

Triterpenes

These are generally 30 C compounds and closely resemble sterols in their properties, and indeed up to 1948 they were considered to be sterols. They are widely distributed, particularly in ferns and fungi and as sapogenins in most commerical saponin-bearing materials. Triterpenes are now placed in two broad groups, tetracyclic and pentacyclic. The typical tetracyclic triterpene lanosterol (C 30) is now considered as the biogenetic precursor of cholesterol (C 27), which is formed by the stepwise loss of 3 carbon atoms. Knowledge of how exactly this proceeds has relied partly on experiment and partly on speculation. The isolation of three substances, senexonol, senexone and senexdiolic acid, from the wood-rotting fungus *Fomes senex*[6], has furnished unequivocal evidence for the elimination of one of the carbon atoms which rested earlier on speculation.

The pentacyclic triperpenes are of various types, with ring E either 6- or 5-membered. Of these, the former were known earlier. From the Ayurvedic antidiabetic drug *Salacia prenoides*, five completely new friedelane derivatives were isolated and their structures established[7]. Prominent among the 5-membered E ring triterpenes are fernane and adianane derivatives. A large number of these compounds were isolated from Indian ferns.

From another Ayurvedic anti-diabetic drug, *Salacia macrosperma*, the most rare group of compounds known as quinone methides were isolated. A very extraordinary member is salacia quinone methide. It has an extended conjugation compared with all known quinone methides and most surprisingly ring C is 5-membered[8].

Skimmiwallichiin from *Skimmia wallichii* is a C_{34} tetracyclic triterpene methyl ether. It has a 19 cyclo structure and uniquely has an isopropyl group at position 23[9].

Campanulin from *Rhododendron campanulatum*, serratagenic acid from *Clerodendron serratum* and caccigenins A, B and C from the Unani drug Gauzaban (*Caccinia glauca*) are all new triterpenes isolated by Rangaswami's group.

Saponins

These are glycosides in which the non-sugar portion is either a steroid or a triterpenoid; the latter are more common. The sugar components of saponins are invariably more than three and up to seven have been known. Prior to the work of Rangaswami, work on saponins in Indian laboratories was confined to ascertaining the individual genins and the individual sugars (and occasionally their numerical ratios) in the overall mixture. Detailed procedures were standardized in Rangaswami's laboratories for the isolation of individual saponins and for establishing the detailed chemistry, complete in every respect, including the arrangement of the sugars and the inter-sugar linkages and stereochemistry, and the hook-up to the genin moiety. New techniques introduced were partial hydrolysis, stepwise hydrolysis, removal of terminal sugar, permethylation, lithium aluminium hydride reduction, borohydride reduction and periodate oxidation. By a judicious combination of these techniques, and application of Klyne's rule of molecular rotations, the structures of the saponins of several Indian drugs were investigated. Typical examples are the saponins of *Achyranthes aspera*[10,11] and *Putranjiva roxburghii*[12].

The alkaloid lycorine and its relatives have been isolated from several cattle poison plants and a new alkaloid, norneronine, was obtained[13] from *Pancratium longiflorum*. Rotenone and related compounds were isolated from several insecticidal *Tephrosia* species of South India. These contain in addition new isoflavones called maxima substance A, B and C[14]. The wood-rotting fungus *Fomes fomentarius* contained an extremely unusual succinic acid derivative designated as fomentaric acid; it is α-methyl, $\beta:\beta$-dioctadecyl succinic acid[15].

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C N R Rao

Solid state chemistry, chemical spectroscopy and molecular structure, and more recently surface science, have been my major areas of research. Developments in structural chemistry, specially chemical spectroscopy and molecular structure, made a great impression on my generation of chemists and I took up research in these areas in the early 1950's. Three great men who really inspired me in the early years were Linus Pauling, C V Raman and H C Brown. Around 1956, I thought that solid state chemistry offered tremendous scope for research, especially when modern tools of characterization and structure determination are employed and over the years, this area has become my prime preoccupation. In solid state science, I was specially inspired by Nevill Mott with whom I have had the fortune to collaborate. In the last decade, I have also got interested in investigating surfaces of solids (under ultra-high vacuum) employing techniques of electron spectroscopy. A brief account of the nature of research efforts made in my laboratory in the last 25 years in these areas is given here. While scientific research has been the only absorbing passion I have had, it is possible that the results of my research efforts may not measure up to the high standards expected in the present-day competitive science. I can only state that I have thoroughly enjoyed working with my students and colleagues and only hope that our research results make worthwhile contribution to the literature.

(1) Solid State Chemistry

When I started research in solid state chemistry, there were very few practitioners in this subject. I have attempted to contribute to various important facets of this interdisciplinary frontier area for the past 30 years. A monograph written in 1978 (with K J Rao) attempts to present a unified treatment of phase transitions in solids and covers theoretical and structural aspects as well as material properties. Besides phase transitions, other aspects of interest to me in solid state chemistry are novel synthetic methods and structures, electron transport and magnetic properties and defects in ionic solids. My coworkers and I have employed a variety of experimental techniques, including high resolution electron microscopy (direct lattice imaging), electron spectroscopies, Mössbauer spectroscopy, X-ray spectroscopy, diffraction methods, etc. to investigate several problems of vital interest.

Structure-property relations in complex solids as well as fashioning solids with desired properties have formed major

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themes of research. A variety of metal oxides and sulphides have been investigated to find unified models for their behaviour. For example, in the series of perovskites of the type $LnBO_3$ (Ln = La or rare earth, B = transition metal ion), the effects of Ln and B ions on the electronic and magnetic properties have been examined extensively. Ferromagnetic and metallic oxides of the type $Ln_{1-x}Sr_xCoO_3$ have been investigated. Two-dimensional oxides of the type La_2BO_4 possessing the K_2NiF_4 structure have been explored. Thus, La_2NiO_4 is found to show antiferromagnetic ordering as well as a metal-insulator transition only in the *ab* plane. Besides, several oxides exhibiting metallic properties, systems such as $LaNi_{1-x}M_xO_3$ (M = Mn, Co, etc.) exhibiting composition controlled metal-non-metal transitions, have been investigated.

Synthetic strategies have been developed to prepare unusual solids, some of them being metastable. The solid solution precursor method wherein the diffusion distance is reduced to 10 Å is one such innovation; several such precursors, including carbonates, nitrates and hydroxides, have been employed. Typical examples of novel solids investigated are: $La_2Ni_2O_5$ with a vacancy ordered superstructure (where Ni^{2+} has square-planar and octahedral coordinations) prepared by the topotactic reduction of $LaNiO_3$; oxides of the type Ca_2MnFeO_5 with Fe_{3+} in octahedral and tetrahedral sites and Mn^{3+} with square-pyramidal coordination prepared by the topotactic reduction of perovskite oxides; $Mo_{1-x}W_xO_3$ $(0 \leqslant x \leqslant 1)$ by the topotactic dehydration of their monohydrates; intergrowth bronzes of the type Bi_xWO_3, where one-tunnel wide strips of the hexagonal tungsten bronze of Bi appear periodically in the WO_3 structure. Intergrowth structures, especially those possessing recurrent periodicity, are fascinating systems investigated in my laboratory recently. The origin of long-range periodicity in such ordered intergrowth structures and also in polytypes has been of considerable interest. Models to explain such long-range order have been examined.

Phase transitions form an important aspect of modern solid state science. Besides investigating structural phase transitions in several inorganic and organic solids employing a number of techniques (spectroscopic, calorimetric, diffraction, etc.), spin-state transitions (in transition metal complexes and oxides), metal-insulator transitions (in metal oxides), localized to itinerant *d*-electron transitions in oxide systems and valence fluctuation in rare earth systems have been studied in depth. Several spectroscopic probes have been employed to investigate the nature of the glass transition and transitions involving orientationally disordered states. The nature of thermal hysteresis in phase transitions has been unravelled. Monte Carlo simulations of phase transitions involving the plastic crystalline and glassy states as well as molecular crystals have been carried out employing realistic pair potentials to obtain valuable insights; the simulations have employed variable volume and variable shape cells.

Several novel and emerging physical techniques have been employed for solid state studies. These techniques have provided new probes to understand several phenomena. For example, X-ray absorption spectroscopy, electron energy loss spectroscopy and Auger spectroscopy have been used to determine the number of valence electron states in solids, just as X-ray photoelectron spectroscopy has been used to investigate mixed valency and metal-insulator transitions as well as spin-state transitions.

Theoretical investigations of the formation, interaction and migration of defects in ionic solids have been carried out. In these studies, a large defect region has been employed to avoid dielectric catastrophe and crystal-independent potential parameters are used. Ionic potentials have also been used to examine phase transitions in alkali halides.

Efforts are being made to initiate investigations on solids employing magic-angle spinning NMR spectroscopy.

A monograph entitled, "*New directions in solid state chemistry*" (written with J Gopalakrishnan) (Cambridge University Press) is under publication. A volume entitled "*The metallic and the non-metallic states of matter*" (edited with P P Edwards) has just been published (Taylor and Francis, London, 1985).

(2) Surface Science

New techniques involving X-ray and UV photoelectron spectroscopy, Auger spectroscopy, electron energy loss spectroscopy, etc. have been developed to probe surface electron states and adsorbed molecules. The first surface science laboratory in the country was established at the Indian Institute of Science, Bangalore, in 1977. Special mention may be made of the discovery of a novel Auger technique for studying the density of valence electrons. Interatomic Auger transitions in solids have been characterized. Surface oxidation of metals and metal glasses, electronic phase transitions and mixed valency in solids are some of the phenomena examined employing the surface techniques. Characterization of molecular oxygen adsorbed on metals is one of the important problems investigated. Semiempirical calculations have been carried out on molecules adsorbed on metal clusters. Vibrational electron energy loss spectroscopy in combination with UPS and XPS is being used to investigate adsorption of various molecules on the surfaces of single crystal and polycrystalline metals and alloys. Auger spectroscopy has been shown to provide fingerprints of adsorbed species. A novel innovation has been to investigate simulated catalysts prepared *in situ* in the electron spectrometer.

A photoacoustic spectrometer has been built in the laboratory and several problems related to solids and suraces have been investigated using the technique. FTIR spectroscopy of surface species by the IRAS technique is being initiated.

(3) Chemical Spectroscopy and Molecular Structure

Much of my research in the early years of my career pertained to the general area of molecular structure. In particular, electronic and vibrational spectroscopy were employed to investigate a variety of chemically significant problems which included spectra-structural correlations, environmental effects, normal vibrational analysis and so on. I authored three major books in optical spectroscopy between 1960 and 1970 and they are still in circulation. UV photoelectron spectroscopy and electron energy loss spectroscopy of free molecules have become of great interest to me in the last few years and this effort has been possible because of the indigenous fabrication of instruments.

A variety of problems involving electron donor-acceptor interactions and hydrogen bonding have been investigated using spectroscopic and theoretical methods. Interaction of alkali and alkaline earth metals with peptides has been studied by X-ray crystallography as well as spectroscopy and theory. *Ab initio* calculations have been made to investigate hydrogen bonding and lithium bonding. Electron energy loss spectroscopy and UVPS have been employed recently to study EDA interactions.

Epilogue

When I started my career as a young lecturer at the Indian Institute of Science, Bangalore in 1959, we had very few facilities for modern chemical research. I was supposed to do spectroscopic research, but there was no spectrometer worth the name. The only instrument we had was a manual UV spectrophotometer. I had to get infrared spectra recorded in other laboratories and had to wait for over five years to get reasonable facilities (at IIT, Kanpur). Yet, some of the works carried out in my early career have become citation classics and I feel specially happy about this. Lack of adequate facilities and support at the right time in one's career is a serious matter and the time gap between having an idea and executing it is a matter of concern that affects the quality of one's contributions to science. Fortunately, the situation has been improving in the last few years.

I would like to express my sincere thanks to my students and other coworkers for their unstinted cooperation and support in my research efforts and to my teachers who encouraged me. My thanks are due to the authorities of the Indian Institute of Science, Bangalore, and the Indian Institute of Technology, Kanpur, where I have carried out most of my work. I acknowledge the support from the Department of Science and Technology, Government of India and the University Grants Commission for my research.

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K J Rao

Among the topical problems of physics and chemistry at the present time, the nature of glassy state is perhaps the most important one. Glasses are metastable, have genetic imprint of the parent liquids from which they are quenched, possess no long-range order and defy stoichiometric principles. Generalizations related to structures and properties of glasses have almost always turned out to be non-universal. From the point of view of physical chemistry, the role of the nature of bonding which determines the structure and stability of glasses is of supreme importance. Accordingly, a broad-based experimental programme of in-depth investigations on glasses with several bonding types has been carried out.

Ionic Glasses

Sulphate glasses based on zinc sulphate-alkali sulphate system have been examined in detail in both binary and ternary compositions (with alkali couples). The glass-forming regions (phase diagram), molar properties, glass transition, crystallization behaviour, ionic transport, etc. have been investigated. The relevance of a modified model with random close packing of spheres has been examined. In essence, the model assumes that Zn^{2+} ions are always present in octahedrally coordinated positions, as evidenced from optical spectroscopy and electron spin resonance studies of doped divalent transition metal ions; K^+ ions occupy the tetrahedral voids generated in the random close packing of the pseudospherical SO_4^{2-} ions in such a way that they are coordinated to 12 oxygens, three each from the four surrounding sulphate ions. Na^+ ions also occupy similar tetrahedral voids, but acquire an eight-coordination with oxygen (two each from the four surrounding SO_4^{2-} ions). Based on such a model, insight has been gained with regard to glass formation in such discrete anion glasses (DAG). The glass forming region corresponds to compositions which give rise to highest configurational entropy densities. The viability of rcp-based model of DAG is supported by X-ray diffraction studies of both binary and ternary glasses.

From dc electrical conductivity studies in mixed alkali compositions it was found for the first time that the DAG system also exhibits mixed alkali effect. This effect has been shown to be primarily due to structural effects. The ac conductivity and dielectric studies revealed the existence of an activation barrier considerably lower than in the dc conductivity studies. Such difference between ac and dc conductivity barriers is again consistent with the rcp model, which provides for local hopping of alkali ions in the neighbourhood of Zn^{2+} ions between potential wells separated by

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lower barriers. The nature of magnetic interaction of doped transition metal ions at sufficiently high concentrations (5-10%) was investigated through magnetic susceptibility measurements. It was found that the susceptibility behaviour was paramagnetic up to very low temperatures; extrapolation suggested weakly ferromagnetic interactions.

A major attraction of ionic glasses in recent times has ensued from the possibility of making fast ionic conducting glasses and their eventual use in fuel cells. $AgI\text{-}Ag_2O\text{-}MoO_3$ glasses which exhibit fast ion conduction have been investigated in detail. Molybdenum is present only in four coordinated MoO_4^{2-} ions, as in alkali molybdates.

Covalent Glasses

Several covalently bonded chalcogenide glasses have been studied in detail. The notion of chemical ordering has been shown to be a useful structural principle in understanding the behaviour of chalcogenide glasses. In As-Se glass system, the composition was varied on either side of the stoichiometric $As_{40}Se_{60}$. Due to chemical ordering, homoatomic bonding (either As-As or Se-Se) types are present exclusively on any one side of $As_{40}Se_{60}$ compositions. The occurrence of the density maximum, variations in the microhardnesses, behaviour of the glass transition temperature, dependence of the dielectric constants and of diamagnetic susceptibilities were all found to be consistent with a chemically ordered network model (CONM). The variations in K-absorption edge chemical shifts were also found to support CONM; qualitative molecular orbital arguments were used to show the consistency.

The electrical transport behaviour of As-Se glasses was investigated over wide ranges of temperatures and compositions. Besides establishing that As-Se glasses behave differently from other semiconducting non-chalcogenide glasses, it was shown that the existence of conjugate defect pairs could account well for their transport behaviour. It was shown that in a variety of chalcogenide glasses reported in literature, the energies required to create conjugated pairs of defects were always very close to the dc conductivity gap. Further, it is in the very nature of these conjugate pairs that the coordinated positive defect centres can switch positions with other 'candidate' centres; that is perhaps the reason why the Seeback coefficients in chalcogenide glasses are almost universally positive.

$K_2O\text{-}MoO_3\text{-}P_2O_5$, $PbO\text{-}MoO_3\text{-}P_2O_5$ and $PbO\text{-}PbX_2$ ($X = F$, Cl) glasses have been investigated in great detail to understand the role of octahedral units in the glass structure. The structures of these glasses consist of networks built of octahedra. X-ray diffraction, EXAFS, ESR and optical spectroscopic studies have been used to show that (PbO_2X_4) ($X = F$, Cl) units are present in all glass compositions. The presence of (MoO_6) units in phosphomolybdate glasses has been established through IR optical absorption and ESR studies. Severely modified glasses consist of MoO_4^{2-} units (discrete anions). Pb^{2+} ion in lead phosphomolybdate glasses acts both as a network former and as a modifier. ESR and ultrasonic studies have been used to investigate this behaviour. The role of Pb^{2+} is intimately associated with the concentration of P_2O_5 in the glass. A new method of understanding complex glass systems on the basis of structural phase diagrams has been developed.

Glass Transition

The phenomenon of glass transition is a distinguishing feature of glasses whose complete understanding has not been achieved so far despite various experimental and theoretical investigations. It has come to be increasingly realized that glasses are essentially made up of clusters joined together by inter-cluster material of lower density. It is also possible that in glasses, a certain degree of compositional fluctuation is tolerated. Experimental confirmation of cluster formation was considered imperative in order to unertstand glass transition. A variety of experimental techniques, such as ESR, infrared, Raman and Mössbauer spectroscopies, high resolution electron microscopy, high pressure conductivity, etc., have been used to show that cluster model is quite viable for glasses. A theoretical model of glass transition has been developed incorporating the notion of cluster-tissue texture of real glasses. The model establishes conceptual links for glass transition with other solid state phase transitions.

Glasses and Nature of Bonding

The role of the nature of bonding in relation to glassy state itself has been investigated. The X-ray absorption chemical edge shifts and L-edge absorption intensities have been related to the ionicities and it has been shown in a variety of glasses, such as ThF_4-HfF_4, NdF_3-BeF_2, PbO, PbX_2 (X = F, Cl), etc., that the bonding is substantially more covalent in the glassy state than in the crystalline state. Studies performed in PbO-$PbCl_2$ glasses over a wide composition range have enabled semiquantitative correlation between glass forming tendency and ionicity.

Local Structure Studies Using EXAFS and XANES

In recent years, structural investigations in the glassy state have benefitted immensely from the use of a relatively new technique—Extended X-ray Absorption Fine Structure (EXAFS) analysis. The strength of this technique lies in the fact that it is atom selective. Application of EXAFS in the present state of its theoretical development enables one to obtain fairly accurate interatomic distances (±0.02 Å) for the first and second shells of atoms around the absorber. It also enables determination of the number of neighbours to a fair degree of accuracy (±10%). The EXAFS technique has been extended to analyse several glass forming systems, such as NdF_3-BeF_2 glasses. EXAFS analysis was performed for both L_{II} and L_{III} edge absorptions associated with Nd^{3+} and a coordination number of 7 was obtained from both sets of data. EXAFS associated with L_{III}-edge of lead was analysed in PbO-PbX_2 glasses using phase shift parameters obtained from EXAFS analysis of crystalline PbO and $PbCl_2$ and it was shown that the first coordination shell of lead in all glass forming compositions consisted of 2 oxygen and 4 chlorine atoms. That the increase in covalency is a concomitant feature of glassy state itself could be established by examining the EXAFS and XANES of ThF_4-HfF_4 glasses. This is a unique glass system in that the coordination number of Th is equal to 8 in both crystalline and glassy states. But at the L_{III}-edge of Th, absorption intensity is much higher in the glass than in the crystalline phase, which is possible only because of the increased covalency in glassy state, thereby proving the point. Perhaps this is the first time that the intensity data in XANES have been used to analyse the nature of bonding. It has been possible to relate the near edge absorpition coefficients with the ionicity through theoretical expressions based on the use of shielding constants.

Pressure Effect in Glasses

Absence of periodicity which characterizes glassy state entails metastability. It is, therefore, to be expected that this metastability of glasses is affected by the application of pressure. The effect of pressure, which often results in crystallization, can be monitored in ionic glasses by measuring ionic conductivity. Pressure studies in fast ion conducting glasses, in which a unique conductivity-pressure behaviour has been observed, have been used to provide compelling evidence for the cluster model of glasses.

Similar pressure studies on the crystallization of PbO-PbF_2 and PbO-$PbCl_2$ glasses have not only proved the applicability of cluster model but have provided evidence for the presence of (PbO_2X_4) $(X = F$ or $Cl)$ unit corner-connected through oxygens. Such (PbO_2X_4) units constitute the basic structural units in these glasses.

Rao has also made contributions in phase transitions related to a number of crystalline solids where novel features, such as commensurate-incommensurate cooperative and other structural aspects, have been found to be involved.

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P S Rao

The research career of P S Rao can be broadly divided into three phases. The first phase comprises his association with the Andhra University (1935-1945) where he worked under Prof. T R Seshadri, FRS. Apart from the thesis work for the MSc (Hons) degree, which comprehended studies on geometrical inversion in the acids derived from coumarins and reactivity of the double bond in coumarins and related α,β-unsaturated carbonyl compounds, the main investigations related to the pigments of flowers, particularly anthoxanthins and their glycosides. The aglycones were studied by the classical methods developed in western laboratories involving alkaline degradation, oxidation, etc., and identifying the degradation fragments. It was found that in these experiments it was more advantageous to degrade the methyl ethers. A search for new methods of methylation was, therefore, warranted; earlier methods of methylation were not quite satisfactory, because they did not effect complete methylation of all the hydroxyl groups, particularly the one in position 5. Rao developed a new method of methylation through the acetyl derivatives. The latter were treated with alkali and dimethyl sulphate under controlled conditions, when simultaneous deacetylation and methylation took place and the fully methylated derivatives of the anthoxanthins were produced. This method, which came to be known as the method of Rao and Seshadri, was particularly useful for establishing the structures of glycosides, since the fully methylated glycosides, on hydrolysis, would yield monohydroxy polymethoxy aglycones, wherein the position of the free hydroxy group would indicate the original position of the glycosidic group. Adopting this method, the structures of gossypitrin, herbacitrin, quercetagitrin, cannabiscitrin etc. were established. The structures of cannabiscetin and hibiscetin were also determined by both degradation and synthesis. The flavanone glycoside butrin was shown to be a diglucoside, containing the sugar residues in 3′ and 7 positions. From the flowers of *Hibiscus sabdariffa*, another new pigment, sabdaritrin, was isolated, but its structure could not be determined at that time, although the structure of its aglycone had been established.

With the then existing knowledge, a scheme of evolution of the various types of anthoxanthins was developed and put forward. It was an extension of the theory of Robinson *et al.* regarding the biogenesis of anthocyanins, which involves a parallel origin from a common precursor derived from a C6 and a C9 unit.

During the second phase of his research

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career, which coincides with his stay at the Forest Research Institute, Dehradun, Rao engaged himself in investigations on the chemistry and utilization of several forest products like fatty oils, essential oils, carbohydrates, proteins, tannins, etc. Among these, mention may be made of the development of the tamarind kernel powder (TKP) industry. During the later part of the second world war, the food situation in the country became so serious that it was not possible to divert any of the foodgrains to industrial uses. Consequently, the Indian textile industry, which used to depend on cereal starches for sizing and finshing, was faced with the prospect of closing down for want of sizing materials. The Forest Research Institute, Dehradun, therefore, undertook a systematic examination of the available forest resources which were likely to yield either starches or starchy materials to serve as sizing materials, and it was discovered that the kernels of tamarind seed (*Tamarindus indica* L.) contain one such substance. Soon TKP came to be produced in large quantities at both factory and cottage-scale levels. This discovery released cereal starches for human consumption, which were otherwise used up in the industry, to such an extent as to feed the entire nation (undivided India) for a day. The constituent carbohydrate, named tamarind seed jellose (TSJ), was shown to be a new class of neutral polysaccharides composed of glucose, galactose and xylose, possessing excellent jellying properties. Its structure was also established tentatively. It was during this period that Rao developed the upward-migration and circular methods of paper chromatography for the identification of sugars, uronic acids and amino acids.

Methods for utilizing some of the forest tubers like diascoreas (*D. hispida* Dennst and *D. bulbifera* L. and other species), *Pueraria tuberosa*, etc. for the production of edible starches were worked out. Several gums, mucilages and hemicelluloses were studied during the course of investigating substitutes for imported gum arabic. TKP was also found to yield a good label paste.

Among the essential oil-yielding materials which were studied from the point of view of isolation of the oil and studying its composition and utilization, mention may be made of *Coleus vettiveriodes* K C Jacob, *Eucalyptus citriodora* Hooker, *Eucalyptus* hybrid, *Abies pindrow* Royle (silver fir), *Picea morinda* Link (spruce), *Saussurea lappa* C B Clarke, *Valeriana wallichii* D C, *Tylophora indica* (Burm.f.) Merr., *Bursera delpechiana* Poisson, etc.

Cottage-scale methods for the processing of crude camphor, production of agarwood oil, utilization of "exhausted" agarwood for the manufacture of agarbatties, were also worked out.

During this period, a number of cottage-scale methods of utilization of various forest products were developed; notable among these are methods for the manufacture of dehydrated mango pulp (*aam papar*) from mangoes, jujubes from tamarind seed jellose, a dyestuff from teak leaves, katha from khair wood and a fatty oil from Kumaon apricot kernels.

The researches which Rao had undertaken during his association with the Forest Research Laboratory at Bangalore belong to the general areas of plant physiology and plant pathology, with particular reference to the sandal plant, *Santalum album* L., which is one of the most important economic species of India, being the source of the valuable sandalwood oil used extensively in soaps, perfumes and cosmetics. A good proportion of the oil produced in the country is exported to other countries and it is, therefore, a good foreign exchange earner. However, nearly 50 years ago, the plant came under the virulent attack of a foul disease, called spike disease, which began to take a heavy toll every year. One of the main objectives for starting the Forest Research Laboratory at Bangalore was to tackle this disease, and Rao had to face a serious challenge. The disease, which was originally taken to be a virus disease, was shown to be mycoplasmal in nature. The physiology of the plant, both in health and disease, was studied extensively in order to understand the pathological effects of the disease. A simple stain test for detecting the onset of the disease was developed, which facilitated the investigations. Methods for the possible control of the disease, making use of antibiotics and fungicides like benlate, were worked out. Thus, Rao is a unique combination of a forest chemist and a forest physiologist with a good knowledge of forest pathology.

During the course of the above investigations, studies were also made on the vegetative propagation of sandal, accelerated germination of the sandal seed, chimera in the plant, extractives of the heartwood and sapwood, and preservative treatment for the sapwood.

Carving and turning, with the closely allied inlay work, are important specialities of Karnataka State and a variety of articles of entertainment, decoration and utility are produced from a number of woods. The heartwood of sandal, with its sweet fragrance stands supreme among these woods and is employed on a large scale to prepare idols and dolls by carving, batons, walking sticks, rulers, chessmen, chess cases, powder boxes, etc. by turning and small jewellery boxes, cigar cases, flower vases, etc. by handiwork, but the heartwood had become very costly. So experiments on the sapwood, which had been a waste, were conducted and it was shown that the sapwood is also as good as the heartwood for the above purposes. But it is nondurable and so methods of treatment for increasing its durability were worked out, so that the treated wood could be employed with advantage.

Another important work done by Rao during this period was the compilation of information on some Indian aromatic plants. At the Forest Research Institute, Dehradun, the compilation work had been started by R L Badhwar and S Krishna during the late 1940's and Rao had been closely associated with it. After the publication of 16 parts, the work could not be continued for one reason or the other. Rao, after coming over to the Forest Research Laboratory at Bangalore, resumed the compilation and completed the job by publishing six more parts. He plans to bring out a monograph on "Aromatic Plants of India".

On the laboratory side, Rao is currently engaged in investigations on the "pigments" of white flowers. There are very many cases where there are distinct differences in colours, although the flowers belong to the same species, the colours varying from white to orange and even red. This type of colour variation is also noticed frequently in flowers belonging to different species in the same genus. What is this variation due to? Possibly it is on account of some small chemical changes like methylation in the structures of the constituent pigments of the coloured flowers which usually happen to be anthocyanins, anthoxanthins and related products.

Rao has so far published about 180 scientific articles and is the joint author of three books: (1) Industrial Gums, (2) Some Useful Aromatic Plants, and (3) Handbook of Indian Woods and Wood Panels.

Rao was elected Fellow of the Indian Academy of Sciences (1943), a Fellow of the Royal Institute of Chemistry, London (1952), a fellow of the Indian National Science Academy (1968), a Fellow of the Indian Academy of Wood Science (1968) and a Fellow of the Indian Academy of Horticultural Sciences (1974). He was also an elected Member of the Indian Phytopathological Society and the American Wood Preservers Association. He is a Founder Member of the Tree and Wood Chemistry Group of the International Union of Forestry Research Organisations (IUFRO).

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R P Rastogi

Non-equilibrium Thermodynamics

Experimental and theoretical studies conducted from non-equilibrium thermodynamic angle of several phenomena, viz. thermo-cells, reversible chemical reactions, thermo-osmosis of liquid and gaseous mixtures, Dufour effect in liquids and gases, electro-osmosis, electro-osmotic pressure and streaming potential, sedimentation potential and electrophoresis, showed that linear phenomenological relations are valid for coupled processes and Onsager reciprocity relation is satisfied for all types of phenomena. On the basis of experimental results, non-linear flux equations were suggested for the first time and a theoretical justification for second order terms was given in terms of zeta potential at the double layer. Theoretical analysis of thermal diffusion on the basis of Chapman-Enskog theory showed that fluxes become non-linear when the gradient of barycautric velocity is significant.

Thermo-osmosis of ternary and quaternary mixtures and thermo-osmotic concentration difference in gases were investigated from theoretical and experimental angles for the first time.

Far from equilibrium phenomena were investigated from many angles. Based on thermodynamic theory of instability, it was shown that under certain conditions, instability can occur when an autocatalytic reaction occurs. In this context, it has been proved that in Lotka-Volterra model and Oregenator model of BZ reaction, all the steps are uncoupled in the thermodynamic sense and thus the instability arises mainly due to the presence of autocatalytic subset.

A new class of BZ oscillatory reaction systems containing mixed organic substrates was discovered in the course of investigations on oscillatory reactions. The mixed substrates were acetone + Z, where Z = lactic acid, oxalic acid, mandelic acid, tartaric acid, sucrose, glucose, fructose, maltose, lactose, ascorbic acid, glutathionone or NADPH. Stoppage and regeneration of oscillations by the addition of Br_2, CCl_4, BrO^-_3, Hg^{2+}, Br^- and Ag^+ has been investigated and it has been concluded for the first time that molecular bromine influences the occurrence of oscillations via hydrolysis reaction yielding HOBr. Quantitative studies show that at these limits, $[Br_2]/[Br^-]$ has a fixed value and follows a regular behaviour.

A series of new iodate-driven oscillations have been discovered which occur in batch as well as stirred tank reactors. Here again, it is confirmed that molecular iodine influences the range in which oscillations occur. A new oscillatory reaction system, $Ce^{4+} + I^- + IO_3^- + HCl$, has been discovered which does not contain any organic species.

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Extensive investigations were conducted on the one-dimensional and two-dimensional waves in (i) iodate-arsenite systems, (ii) bromate driven system, (iii) bromate-ferroin system, and (iv) iodate driven oscillatory systems. It has been found that the velocity of propagation (V) for halate driven systems is given by

$$V = k' \ [H^+]_0^{1/2},$$

$$X = IO_3^-, \ BrO_3^-$$

when Ce^{4+} is absent from the system. On the other hand, when Ce^{4+}/Mn^{2+} is present in the system,

$$V = k \ [H^+]_0^{1/2} \ [X]_0^{1/2};$$

$$X = IO_3^-, \ BrO_3^-$$

where k and k' are constants independent of concentration, but these depend on temperature as per an Arrhenius type of equation. Experimental results showed for the first time that for all bromate driven oscillators, the energy of activation has a unique value. Similar was the case for all iodate driven oscillators. It was further discovered that k and n (the number of bands) are related as follows:

$$k = C' - a'n^2$$

where C′ and a′ are constants.

Bistability in iodate-arsenite system and BZ systems containing mixed organic substrates has been investigated in detail along with a detailed study of hysteresis phenomenon. Dissipative structures have been observed in eight BZ oscillators containing mixed organic substrates.

Two-dimensional dissipative structures on porcelain membrane containing a series of blue and red bands were obtained for the first time in B-Z systems when benzene was added.

Using the procedure of non-equilibrium statistical mechanics, an expression for electrical conductivity tensor was deduced in terms of microscopic current autocorrelation, which has been shown to lead to the classical expression for electrical conduction in a Fermi gas.

Rastogi, Das and Batra discovered the phenomena of dissolution and precipitation potential in 1961. Ingenious experiments were designed to dissect the phenomena and a thermodynamic theory was advanced. Experiments were designed to test the hypothesis and theory and the results obtained agreed with theory. Precise values of dissolution and precipitation potentials were obtained by designing new techniques using microelectrode and rotating electrode. A mechanism of development of freezing and melting potentials has been suggested for the first time.

New photo-excited non-equilibrium phenomena, viz. photoelectro-osmosis, photo-potentials and photo-current across chlorophyll impregnated cellulose-acetate membrane have been discovered and studied experimentally leading to a plausible mechanism, theory and a model whose predictions have been tested experimentally.

Propulsion Chemistry

Extensive researches had been undertaken in the fields of propulsion chemistry and rocket propellant chemistry. Combustion of solid, liquid and hybrid propellants has been studied in detail.

A new relationship for pressure dependence of burning rate of composite solid propellants and a new thermodynamic theory of instability of composite solid rocket propellants have been developed. Combinations of linear and crosslinked polymers using ammonium perchlorate as an oxidiser have been investigated. In this context, a detailed study of combination of copolymer of styrene and oxygen has been carried out.

New ideas on the mechanisms of catalyzed and uncatalyzed combustion of composite propellants have been suggested. A new equation for catalyzed decomposition of AP at all temperatures has been suggested which satisfies the available data. A physicochemical model has been suggested which leads to the proposed equation.

In the course of researches on ignition of hypergolic and non-hypergolic fuels, a new catalyst, viz. ammonium metavanadate, was discovered. The problem of auxiliary ignition in liquid rocket motors was investigated and a new oxidiser for this purpose was reported. The concept of mixed fuels (hydrazine + ethyl alcohol) was developed.

A theory of pressure dependence of burning rate of hybrid fuels has been developed. The combustion behaviour of aniline nitrate (solid)/red fuming nitric acid (liquid), aniline-formaldelyde/RFNA and o-toluidine nitrate (solid)/nitrogen tetroxide (liquid), including the mechanism, has been studied.

Boron-containing polymers/oxygen system was subjected to detailed study for which novel experiments and a new theory for interpretation were developed.

Thermodynamics of Mixtures, Phase Equilibria, Chemistry of Eutectics, Addition Compounds and Solid-Solid Reactions

Thermodynamic properties of associated mixtures and addition compounds were investigated with the help of phase diagrams. Formation of molecular complexes between benzene and carbon tetrachloride was established by Rastogi and Nigam in 1959. Thermodynamic properties, viz. heats of mixing, volume of mixing and free energy of mixing of benzene + carbon tetrachloride were measured. The results were consistent with the results obtained from phase diagrams. Studies were extended to mixtures of other aromatics with CCl_4, which for the first time showed that as the number of $—CH_3$ substituents in the benzene ring increased and the electron density of the ring increased, the thermodynamic properties showed increasing complexations. Thermodynamic properties of ternary mixtures were studied and a new correlation between the properties of ternary mixtures and the corresponding binaries was obtained.

Entropy of fusion of molecular complexes could be estimated from novel studies on phase diagrams; the results were found to agree satisfactorily with direct calorimetric measurements. Entropy was also estimated using methods of statistical mechanics. Heats of fusion of eutectics were measured calorimetrically for the first time. Crystal growth of organic eutectics and addition compounds and their microstructures were studied for the first time.

The kinetics and mechanism of solid-solid reactions leading to the formation of molecular complexes from components were also studied for the first time and a number of organic and inorganic systems were investigated. Organic eutectics were studied as media for reactions for the first time.

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K K Rohatgi-Mukherjee

Even in the fifties, modern approach to photochemical studies was hardly introduced in India. Therefore, in order to initiate such studies, we took up a few problems, some of which have given rich dividends and are still pursued with all their ramifications, whereas the others have been dropped. The main thrusts of the work are presented below.

(A) Spectral Studies on Dye Aggregation and Photophysics of Laser Dyes

Dyes as laser materials have found high priority in academic research. A systematic study of photophysics and photochemistry of dyes is, therefore, of considerable interest. With this objective in view, detailed studies of the absorption and emission characteristics of a series of halofluorescein (anionic) and rhodamine (cationic) dyes were taken up. The phenomenon of concentration quenching of fluorescence revealed the importance of dye aggregation[1]. Quenching involves the dimers as the energy traps. An understanding of the nature of bonding in dye aggregation is important for more than one problems, such as stacking interaction in biomolecules, hypochromism and conformation of polypeptides, energy transfer in photosynthetic units of chlorophyll, metachromatia and staining properties of dyes for biological specimens. From spectrophotometric study, dimerization constants and the thermodynamic parameters, $\triangle G$, $\triangle H$ and $\triangle S$, were evaluated[2]. This work established that aggregation in fluorescein at *p*H 12 is an enthalpy directed phenomenon in which water molecules participate in dimer formation, but in rhodamine entropy-directed hydrophobic interactions are involved. These conclusions were confirmed by studying the effect of urea on the fluorescence of aqueous solutions of these dyes[3] as well as by the results of studies on a series of halofluoresceins[4]. On halosubstitution, oscillator strengths (f) or square of the transition moments of absorption $|M|^2$ increase with concomitant increase in the aggregation tendency. The variations in the thermodynamic parameters in the series distinctly establish[5] that the force responsible for aggregation gradually changes from enthalpy-directed one to entropy-directed one.

These ideas could be further substantiated by applying the theory of exciton coupling developed for interactions among chromophores in molecular crystals by Davydov and for weakly coupled systems such as van der Waals aggregates, by Förster, Kasha and others. To apply this theory, it was necessary to isolate the dimer spectra from the observed composite spectra of

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the dyes. An iterative method with the necessary experimental technique was developed[6] to obtain the true dimer spectra which showed characteristic splitting of the monomer band due to dipole-dipole interaction. The strength of interaction is manifested in the energy difference, ΔE, between the split bands which increase with $|M|^2$, as predicted by the theory: $\Delta E = \frac{|M|^2}{R^3} G$, where G is the geometry factor describing the stacking behaviour of the dyes; and R, the interplanar distance. From the angle of twist and inclination between the two components of the dye-dimer the stacking pattern could be established[4,7].

Another interesting aspect of the photophysical properties of the dyes was the energy transfer phenomenon between dyes of similar or closely related spectral characteristics. Such dyes may serve as model systems for the study of energy migration in chlorophyll and other pigment units in plant photosynthesis. A number of correction factors are required to obtain the true value of quantum efficiency of fluorescence[8,9]. It could be established from the rate constant for energy transfer that Förster mechanism was operative. The method developed for correction of the absorption-reemission effect has been used recently to obtain the true excited state lifetime of chlorophyll molecules.

With a view to developing laser materials, some mixed chelates of rare earths were synthesized. Spectral studies[10] on these compounds led to the conclusion that the emission characteristics of these chelates can be improved by the distortion of microsymmetry around the metal ion. The effect depends on the enhancement of the symmetry forbidden electric dipole transition.

(B) Photophysics and Photochemistry of Anthracene Sulphonates

A molecule in the electronically excited state can be said to be a new molecular species with its characteristic nuclear geometry, charge distribution and hence its dipole moment, redox potential, acid-base character, solvation properties and the consequent photophysics and photochemistry. Besides charge-transfer (CT) interactions, new types of interactions may also develop in the excited state, such as exciton interaction. They lead to complex formation (excimers and exciplexes) in the excited state between pairs of molecules, which, in general, may not interact in the ground state. Many of these complexes manifest themselves by their characteristic fluorescence, which is structureless and broad due to repulsive ground state potential. Anthracene has been a favourite hydrocarbon molecule for the understanding of photophysical and photochemical phenomena because of its conveniently located absorption and emission spectra. Early work on fluorescence quenching by halomethanes[11] opened up controversial issues on the mechanism of quenching of fluorescence.

The excited state properties are very sensitive to perturbation. An interesting example is provided by variously substituted anthracene sulphonates, which are soluble in water. These compounds do not differ much in their absorption character consequent to substitution of $-SO_3^-$ group, but show large variations in their excited state properties, although $-SO_3^-$ is supposed to be a weak perturbant. The existence of such interactions in these compounds is immediately apparent from the nature of their fluorescence spectra in aqueous solution[12]. For 1,5- and 1,8-substituted anthracene sulphonates (AS), the fluorescence spectra are structured as in unsubstituted anthracene in benzene, but for 1-AS and to some extent for 2-AS they are completely devoid of vibrational features. Interestingly enough, for 1-AS, vibrational features gradually develop on the addition of acetonitrile (ACN) with concomitant blue shift. The nature of interaction of 1-AS with H_2O is very different from that of the others. This is due to a large change in dipole moment on excitation [$\Delta\mu = 3.6$D(debye); $\mu_e = 4.4$ D; $\mu_g = 0.8$ D)] and absence of any element of symmetry. The excited state lifetime $\tau(H_2O)$ is 7.30 ns as compared to the expected value of 2.6 ns, which is realized in ACN. From these considerations it is concluded that there is a specific interaction in the excited state between 1-AS and a few molecules of H_2O and emission is characteristic of this exciplex[13].

The fluorescence quantum yields, ϕ_f, also differ for these sulphonates: 1-AS = 0.25, 2-AS = 0.40, 1,5-AS = 0.26 and 1,8AS = 0.16. An explanation for such variation has been found from the temperature dependence of fluorescence[14]. An Arrhenius type plot indicates that there is an energy barrier for intersystem crossing which is higher in the case of 2-AS, justifying high ϕ_f. More quantitative studies on the partitioning of the excitational energy through various channels are in progress. Some work using nanosecond flash photolysis technique to measure the triplet-triplet absorption and other triplet energy photophysics has been carried out at the Radiation Laboratory, Notre Dame, Indiana[15]. These sulphonates undergo self-quenching and the consequent excimer formation leading to photodimerization. They undergo photoperoxidation with molecular oxygen, O_2, and act as photosensitizer for oxidation of iodide ion and cause photodynamic action on DNA bases like tyrosin and tryptophan. In these reactions, the role of singlet oxygen, $O_2(^1\Delta_g)$, has been established unequivocally. Mechanistic studies[16] sugget two pathways for photosensitized oxidation of I^- to I_3^- : (i) through the intermediate formation of photoperoxide AO_2, and (ii) by direct CT interaction of I^- with O_2 and subsequent oxidation of IO_2^-, the reaction being solvent polarity and protonicity dependent. Some attempts have been made to identify the reaction intermediates by flash photolysis. These water soluble hydrocarbons are good electron acceptors in the excited state and are quenched by small anions through CT mechanism. Their possible use in redox photochemistry in solution and on organized surfaces such as micelles and vesicles is under investigation. They have also been used as fluorescent probes for microenvironments in micelles and biomolecules.

Electron transfer or charge transfer photochemistry on micelles, on electrode surfaces and in solution is being actively investigated for its specific role in solar energy conversion systems. Some work in this direction using phenosafranine-EDTA[17,18] and novel metal porphyrins aimed at developing biomimetic systems is in progress.

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S S Sandhu

Failure to stabilize an arsenic(III)-copper(II) bond and to obtain complexes of *ortho*-carboxyphenyldimethyl-arsine with nickel(II) and cobalt(II) catalysed the initiation of a plan to synthesize the ligands [$R_2AsC_6H_4COOH$: $R = CH_3$, I; C_6H_5, II; *p*.$CH_3C_6H_4$, III] and to devise a method for obtaining complexes of copper(II), nickel(II) and cobalt(II). Ligands II and III yield complexes with copper(II), while I reduces copper(II) to copper(I) and forms complex with it later[1]. The adducts of the complexes of II and III with copper(II) have also been investigated and octahedral structures have been assigned[2]. The complexes of cobalt(II) with I and II and those of nickel(II) with II and III have been assigned octahedral structure. The nickel(II) complex with I has been shown to be tetrahedral on the basis of its magnetic and electronic spectral data[3].

The complexes of ditertiary phosphines with cobalt(II) and nickel(II) show interesting properties with respect to *n* in $(C_6H_5)_2P(CH_2)_nP(C_6H_5)_2$. The complexes of cobalt(II) halides ($n = 2,3,4$) are tetrahedral, while those of nickel(II) are tetrahedral for $n = 2$. There is an equilibrium between tetrahedral and square planar form for $n = 3$, while for $n = 4$ again the complexes are paramagnetic, favouring tetrahedral structure[4].

Photochemically induced substitution in tricarbonylcyclopentadienyl manganese and its methyl analogue with ditertiary phosphines and arsines yields complexes of the types $C_5H_5Mn(CO)L$ and $[(C_5H_5Mn(CO)_2]_2L$ (ref.5). However, the same technique and the same ligands with sixth group metal carbonyls give complexes of the types $M(CO)_2L$ and $M(CO)_2L_2$, having *cis*-octahedral structure[6].

Ditertiary phosphine and ditertiary arsine oxides have been used to prepare complexes of nickel(II) chloride, bromide, nitrate and perchlorate and octahedral structures have been assigned[7]. Complexes of cobalt(II) nitrate and perchlorate with these ligands have also been assigned octahedral structure[8], while tetrahedral complexes of copper(II) chloride have been obtained with the above-mentioned ligands[9]. The complexes of iron(II) and iron(III) halides, perchlorate and nitrate with oxides of ditertiary phosphines and ditertiary arsines show several interesting features[10-12]. Lanthanum(III), neodymium(III) and samarium(III) chloride also yield complexes with the aforementioned ligands[13].

A study of the photochemical reduction of uranyl ion with dialkylsulphides in acidic medium leads to the oxygen atom transfer

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mechanism, resulting in the formation of uranium(IV) and dialkylsulphoxides[14].

Crystal structure study of two macrocyclic organic compounds, prepared as complexing agents for transition metal ions, led to bicyclic structure; 2,3,8,8a-tetrahydro-5,8a-diphenylimidazo [2,1-c] 1,4-thiazine and 2,3,8,8a-tetrahydro-2-methyl-5,8a-diphenylimidazo [2,1-c] 1,4-thiazine, contradicting the earlier observations based on ^{1}HNMR and ^{13}C NMR data[15,16]. Diorganotin(IV) derivatives of phthaloyl N-protected amino acids have been prepared and assigned *trans*-octahedral and five coordinated structures on the basis of Mössbauer spectra[17,18].

Both oxygen atom transfer and hydrogen abstraction mechanisms are invoked in the reactions of uranyl ion with different kinds of substrates. Nonaqueous media involving protic and aprotic solvents may be helpful in resolving the differences of opinion about the photochemical reactions of uranyl ion and experiments are being planned in this direction.

Peptides coordinate from terminal amino group besides carboxylate group, but under certain specific conditions, deprotonation of -NH and consequently its coordination to metal ion has been reported. The N-protected peptides mimic naturally available cyclic peptides and reactions of these with metal ions and specificity for metal ion, if any, will provide useful information in understanding the biological problems, especially those relating to metalloenzymes. Studies related to molecular structure of these complexes will provide valuable information as to the role of metal ions in these reactions.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M Santappa

(1) Polymer Chemistry

(i) *Thermal Initiator Systems*

Thermal polymerization of vinyl monomers in aqueous solutions with heavy metal ions Ce(IV)[1] and Co(III)[2] without reducing agents as catalysts was observed to proceed with ease. The use of such catalysts stands in sharp contrast to the conventional redox type of catalysts used involving Ce(IV), Co(III), V(V)[3], Cr(VI), Tl(III), Mn(III), Fe(III), $P_2O_8^{2-}$, $S_2O_8^{2-}$ and ascorbic acid; in all cases production of initiating radicals was from the substrate reducing agent. But the nature of initiation by Ce(IV) and Co(III) without reducing agents was proved to be due to monomer radicals and not OH radicals from water. Thallium (III) acetate was found to initiate vinyl polymerization both thermally and photochemically with many novel features. Manganese (III) acetate was found to initiate vinyl polymerization at high temperatures and also at 0°C. A comparison of kinetic parameters in the polymerization of acrylamide and methacrylamide with manganese (III) acetate as initiator led to interesting conclusions regarding absolute reactivities of monomers[4,5]. $P_2O_8^{2-}$ + Ag system[6] was found to be a good water soluble and facile initiator.

(ii) *Photochemical initiators*

New photosensitizers used were: (1) the ion pairs, $Fe^{3+}X^-$(X^- = hydroxide, halide, azide, citrate[6], oxalate ions, etc.), (2) the system of dye (uranine type) + a reducing agent (ascorbic acid), (3) mono- or di-azido, halo- or nitrito cobaltamine complexes, (4) the system anthraquinone sulphonate + halide ion, and (5) uranyl ions[7]. The modes of decomposition of (1) and (3) followed electron transfer mechanism (before or after excitation) with the production of radicals or radical ion initiators. The modes of sensitizing action of (2) and (4) were somewhat similar. The mode of the sensitizing action of (5) was found to be unique and conformed to the excitation of the uranyl ion in the primary photochemical reaction followed by transfer of excitation energy to vinyl monomer in a dark reaction, no electron transfer reaction to monomer being involved. It was demonstrated that thallium (III) acetate gave better performance as a photochemical initiator than as a thermal one. Copper (II) complexes with amino acid ligands, glutamic acid, aspartic acid and serine were found to initiate photopolymerization. The kinetics of bulk polymerization of methylaryloxy methacrylates initiated by γ-rays were studied.

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(iii) *Sysnthesis of New Polymers*

(a) *Condensation polymers* : Studies on condensation polymerization involving alkyl phenols and formaldehyde were made and a colorimetric method for the estimation of methylol phenols was standardized[8]. A new series of polyphenylene oxides and polyamides with azo and azo dibenzamido units were synthesized and characterized as high temperature polymers. Condensation kinetic studies on mono- and di-methylol *t*-butyl phenols and formaldehyde were made.

(b) *Graft copolymers* : Polymethylmethacrylate was grafted onto chlorinated rubber and PVC by the simple chain transfer process. Through viscosity and light scattering studies on these graft polymers it was proved that there were about 50 grafts of poly (methyl methacrylate) per backbone of rubber molecule.

(iv) *Properties of Macromolecules in Solutions and in the Solid State*

Studies on configurational properties of poly (methyl methacrylate), poly (ethyl methacrylate), poly (butyl acrylate co-methyl methacrylate) and the alternative copolymer, poly (styrene-co-methylacrylate)[9] by light scattering, viscosity and osmotic techniques yielded results with regard to thermodynamic nature of various solvents as well as interaction and other parameters. Bulk polymerization of styrene and acrylonitrile was carried out under controlled conditions to get an alternating copolymer of 1 : 1 composition, the structure of which was confirmed by NMR. It was postulated that not only the average composition and molecular weight heterogeneity but also the sequence distribution of the monomer units played a significant role in influencing the dilute solution properties. The relationships among molecular weights, intrinsic viscosities, the rms end-to-end distances and the second virial coefficients were established in various solvents[10]. Polysaccharide samples of plant origin were characterized by light scattering to get molecular weight distributions. The polymer composition and reactivity ratios of copolymer samples of acrylonitrile and vinyl pyrrolidone were determined by infrared spectroscopy. GPC was used for characterizing copolymers. The stereotacticity and reactivity ratios of acrylate copolymers were investigated through extensive NMR studies. Studies on tensile properties of blends of polymers, carbon fibres[11], syntans and immobilization of enzymes on copolymers[12] were carried out and interesting conclusions were arrived at.

(2) Photochemistry

(i) *Photochemical Oxidation Reactions*

When uranyl ions were used for photo-oxidation of formaldehyde, acetaldehyde and isopropanol, it was found that the primary photochemical reaction was the excitation of uranyl ions, which reacted with the substrate in a secondary dark reaction by an electron transfer process, to give uranous ion and substrate radicals. Complementary studies by uranyl ion fluorescence quenching involving substrates and monomers were also made.

(iii) *Photodecomposition of Azidoamine Cobaltic Complexes*

Studies on the photodecomposition of azidopentamine and diazidotetramine cobalt complexes were made using a specially developed ingenious gasometric technique. The dependence of the rate of nitrogen evolution by the photodecomposition of the complexes on various parameters was noted.

(3) Chemical Kinetics

(i) *Oxidation Kinetics*

Mechanistic studies on the oxidation of various aliphatic alcohols, aldehydes, ketones, water and heavy water, mono- and di-basic acids by $S_2O_8^{2-}$ and peroxodisulphate, revealed unambiguously that free radical intermediates SO_4^- and/or OH were involved and that ionic mechanism was absent. Oxidation of all the substrates could be explained either on the basis of homolytic fission of $S_2O_8^{2-}$ or interaction of $S_2O_8^{2-}$ with water, yielding OH and SO_4^-.

Extensive studies on the oxidation of various types of organic substrates by Ce(IV)[13] and Co(III) in various acid media led to the interesting conclusions that (i) ceric ion oxidations involved formation of the complex ceric-substrate, which unimolecularly decomposed to yield radicals and various products, and (ii) the active species may be hydrated metal ion Ce^{4+} and/or its hydrolysed species, $Ce^{4+}OH$, or sulphato complexes of the type $Ce^{4+}SO_4^{2-}$, etc., depending upon the experimental conditions. Co(III), on the other hand, did not form complexes with substrates, but reacted directly with the substrates involving either O-H or C-H or even C-C bond fission of the substrates. A detailed kinetic study of the oxidation reactions of $P_2O_8^{2-}$, peroxodiphosphate, with a wide variety of organic substrates, aldehydes, ketones, alcohols and of H_2O by $P_2O_8^{2-}$ + Ag[14] coupled with studies on product analysis and stoichiometry was made and the kinetic and mechanistic features of the oxidant were explained. The kinetics of oxidative cleavage of oximes (aromatic, aliphatic and cyclic carboxyl compounds) by Tl(III) yielding carboxyl compounds was studied[15]. A unified mechanism was proposed based on the kinetic results. Oxidation and chlorination studies by alkaline chloramine-T have led to our understanding of the mechanism of oxidation by the latter.

(ii) *Hydrolysis Kinetics*

Studies on hydrolysis kinetics of some phenyl (hydrogen) succinates, evaluation of the rates of hydrolysis at different *p*H values and elucidation of the mechanism of hydrolysis were made and applications of these studies in the solubility of drugs and drug modifications were indicated.

(4) Co-ordination Chemistry

(i) *Stability Constants of Metal Complexes*

Extensive work was done on the evaluation of stability constants of binary and ternary complexes of metal ions with various ligands. The metal ions UO_2^{2+} (ref. 16,17), Cu^{2+} and Ni^{2+} are known to form stable complexes with carboxylic acids, amino acids and amines. Equilibrium studies employing spectrophotometry, potentiometry and polarography showed that the mixed ligand complexes were more stable than the simpler complexes. Studies on ternary complexes or mixed two-ligand complexes of uranyl ion with mono- and di-carboxylic acids (75 systems) have indicated the effect of various factors, such as basicity, chelation, steric factors, neutralization, etc. on the stability of mixed ligand complexes. Equilibrium studies on binary and ternary complexes

Cu(III)[18], Zn(II), Cr(III)[19] with bidentate and tridentate ligands were carried out.

Reactions of Co-ordination Complexes in Solution

Kinetic studies on the aquation and base hydrolysis and deprotonation of octahedral cobalt(III)-dimethyl-glyoxime (and ethylene diamine) complexes[20] were carried out, with a view to studying the lability of the cobalt(III)-halogen bond and evaluating the deprotonation constants. Studies were made on the characterization by mass spectrometry and NMR data and amine exchange reactions and tautomerism in the complexes of Schiff bases from Co(II), Ni(II), Cu(II), Zn(II) and 2-amino pyridine and aromatic hydroxyaldehyde[21].

(5) Leather Technology

(i) *Development of Auxiliary Polymeric Compositions for Leather Processing and Finishing*

Non-reactive polyurethane 'lacquers' possessing good drying characteristics were developed bsed on TDI, castor oil, aliphatic amines and alcohols. An improved casein based 'glazed finish' was made by grafting acrylics onto the casein backbone. The possible utility of polyamides and polyurethane aqueous systems in leather processing was reviewed. Organic chemicals of use covering the entire spectrum of leather processing were reveiwed. The possible use of substituted phenol-formaldehyde condensate in the preparation of synthetic tannins was suggested. Studies on the use of lubricants, easy care and other finishes, adhesives, binders, synthans, powders[22] and other top coats, etc. as leather auxiliaries were made. Systematic studies were made on the treatment of tannery effluents, water proofing of sole leather, substituents for wattle, rugby ball leather, urinary, collagen metabolites[23], processing of blood meal, enzymatic unhairing and degreasing of skins, control of salmonella, surface defects in hides and skins and their leathers, fat liquors, development of alternative tannins, dyeing of leathers[24]. Current status and chemistry of vegetable tanning and chrome tanning have been reviewed[25,26].

(ii) *Graft Copolymerisation Reactions*

Graft copolymerisation of vinyl monomers onto pure and modified collagen, gelatin[27], casein, wool fibres, skins, hides and leathers in the presence of thermal and photochemical initiators have yielded very interesting results[28].

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M V C Sastri

Sastri's research contributions during the past 40 years have been mainly in the following areas of physical chemistry, solid state inorganic chemistry and hydrogen energy concept: heterogeneous catalysis, syntheses and structure-based properties of ternary oxides, hydrogen production by photoelectrolysis and hydrogen storage by metal hydrides.

Heterogeneous Catalysis

Sastri's work included studies on solid catalysed vapour-phase reactions and on the chemisorption of the reactant gases on the surfaces of the catalysts, the aim of both types of studies being elucidation of the reaction mechanism and characterization of the active sites. The reactions studied were the synthesis of hydrocarbons and methanol from carbon monoxide and hydrogen and of ammonia from nitrogen and hydrogen, decomposition of alcohols and formic acid in the dual modes of dehydration and dehydrogenation, decomposition of nitrous oxide as a simple indicator reaction for evaluating oxidative activity, and the oxidation of propylene and carbon monoxide.

The earlier researches of Sastri were directed towards the study of the mixed chemisorption of reactant gases, CO and H_2, on cobalt catalysts and N_2 and H_2 on iron catalysts, under near-synthesis conditions. These studies, which were of a pioneering nature, yielded valuable information on the formation of intermediate stoichiometric complexes on the catalyst surfaces and gained worldwide recognition.

The later researches of Sastri concerned the use of ternary oxide systems, such as spinels, perovskites, scheelites, etc., as selective catalysts, particularly for oxidation reactions. His research efforts in this area, though initially aimed at evolving physico-chemical correlations between the structural parameters of the ternary oxides and their catalytic properties have opened up new possibilities and applications such as the following:

(1) Evaluation and utilization of the various types of surface properties (for example, acidic and basic nature of the surface sites) for the desired reaction.

(2) Realization of the importance of matrix effects and geometrical environments of the active ions which could be tailored by appropriate substitution.

(3) Understanding of the relevance of the bulk properties, especially magnetic and electrical properties, in controlling the reactivity of the surfaces.

(4) Realization of the possibility of activating the molecule on the same surface in different modes by suitable

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substitution, which could be advantageously used for selective transformations.

Solid State Inorganic Chemistry

Transition metal oxides have gained considerable applicational importance as component materials in modern solid state devices by virtue of their unique electrical, magnetic and optical properties. Rationalization of the panoramic behaviour of the electrons in transition metal oxides, especially in their ternary combinations with other oxides, is important for the development of fruitful inter-relationship among the chemical compositions, crystal structures and physical (mainly electrical) properties of these systems. With this primary motivation, Sastri initiated a broad-based materials oriented fundamental research programme, which included the synthesis and characterization of new ternary oxide compositions of various structure types and identification of the factors that control their crystal structures and the structure-based physical properties. The study covered the following classes of ternary oxides:

(1) *Vanadates* : $BaVO_3$, $SrVO_3$, $GdVO_3$ $BiVO_3 + x$, $Zn_{1.5}\ V_{1.5}\ O_4$, NiV_2O_4, $(NH_4)_x\ V_2O_5$, $La_xV_2O_5$ and BaV_2O_7

(2) *Cobaltites* : e.g. $LaCoO_3$

(3) *Double perovskites* : $A_2B_2O_6$, e.g. $KLn*Zr_6O_6$, La_2TiCoO_6.

(4) *Molybdates of rare earths* : $Ln*MoO_5$.

(5) *Spinels*, e.g. $Co_{3-x}Ni_xO_4$.

In the preparation of the ternary oxides, new synthetic procedures, like 'precursor' techniques, have been evolved. The electrical transport behaviour of the ternary oxides has been elucidated and rationalized on the basis of the geometric and/or environmental limitations imposed on the ions contributing to the itinerant or localized behaviour of the electrons.

Interfacial Electrochemistry

The kinetics of normally fast ionic reactions, to wit, the reduction of Cu^{2+}, Cd^{2+} and Zn^{2+} ions, on the surface of a dropping mercury electrode (in aqueous sulphate-sulphuric acid medium) were studied using surface-active agents (C_4-C_6 alcohols, benzyl alcohol, cyclohexanol and phenol) as surface retardants. Several features of the inhibition phenomenon were studied. The mechanism of inhibition at high coverages (of the retardants) appeared to be different from that operative at low coverage. At high coverage, the electrode reaction seems to occur through 'pores' created by the compression of surface-actant film.

Hydrogen Energy

The possibility and prospects of using hydrogen as an ideal, non-polluting and inexhaustible fuel substitute for petrofuels has attracted worldwide attention in the wake of the oil crisis of 1973. Realizing the merits of hydrogen as an energy-vector, the Department of Science and Technology of the Government of India, set up in 1976, a special Task Force for Hydrogen Energy, under the Chairmanship of Sastri. In addition, a research project was awarded to him for the production of hydrogen by photoelectrolysis of water using solar energy and its compact storage as metal hydrides. Sastri's work and accomplishments in these areas are summarized below.

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*Ln denotes a rare-earth metal.

(a) *Hydrogen production by photoelectrolysis of water* : Inspired by the earlier work of the Japanese scientists, Fujishima and Honda (1974), a Schottky-barrier cell comprising a compound semiconductor anode, an aqueous electrolyte and a platinum cathode was set up and the photoelectrochemical (PEC) behaviour of a large number of II-VI and III-V compound semiconductors was studied with a view to evaluating their potential utility in the photoelectrolysis of water. These studies culminated in the important finding that Fe_2O_3 doped with TiO_2 possessed the best combination of the desired PEC-characteristics (band-gap = 2.2 eV coinciding with the high-flux region of the solar spectrum, high chemical and dimensional stability and a flat-band potential that required only a small bias-potential) to trigger hydrogen evolution. This work, first reported by Sastri at the Third World Hydrogen Energy Conference held at Tokyo in 1980, has been confirmed and amplified by other workers, notably G Somarjai of the University of California, Berkeley.

(b) *Hydrogen storage by metal hydrides* : Three types of metal alloys—FeTi, Mg_2Ni and $LaNi_5$—were prepared and studied for hydrogen absorption at different pressure levels.

Recently, the thermochemistry of the formation and decomposition of metal hydrides was shown to be applicable in heat pumping applications with important advantages over other types of chemical heat pumps in refrigeration, heat recovery and energy upgradation applications.

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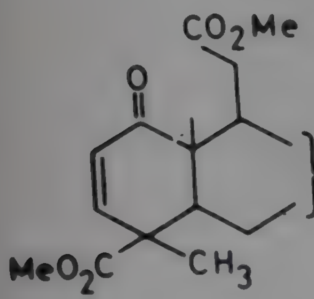
Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

P Sengupta

Sengupta has to his credit notable contributions in the field of chemistry of natural products. The following are among his major achievements: (i) Established[1] the partial structure (I) of the bitter principle, nimbin, (ii) isolated a norditerpenoid nimbiol[2] from *Melia azadirachta* and established its structure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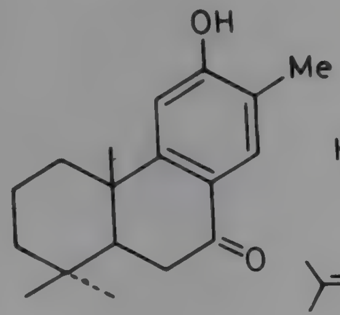

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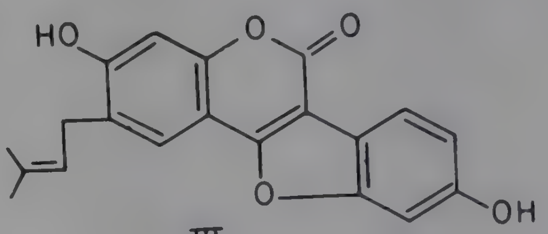

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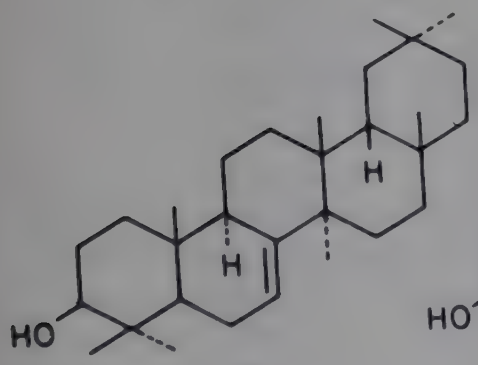

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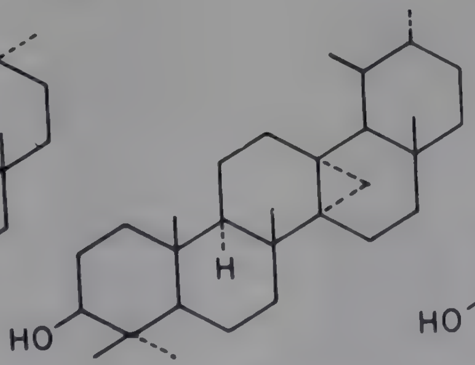

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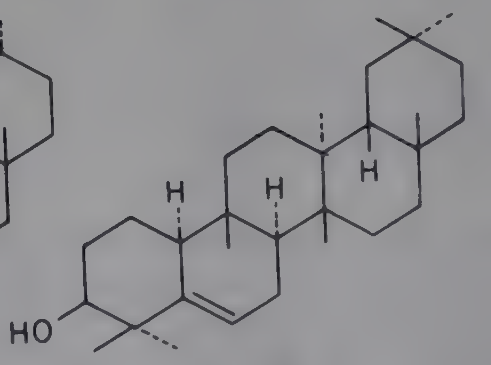

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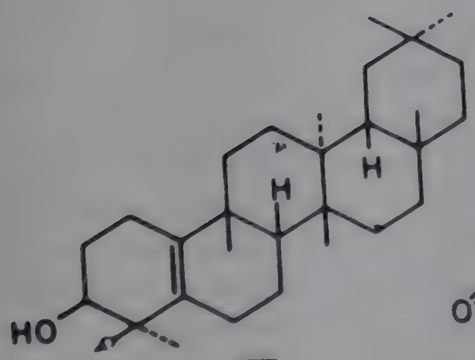

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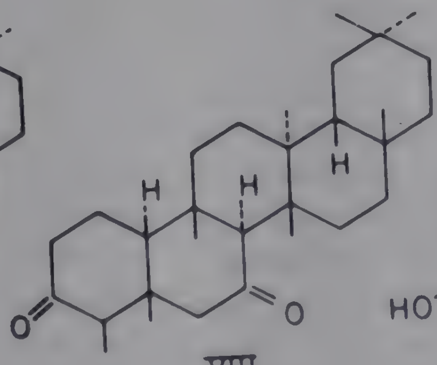

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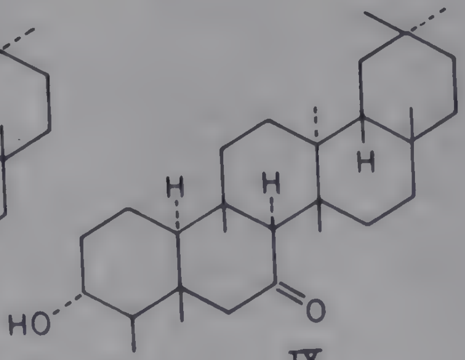

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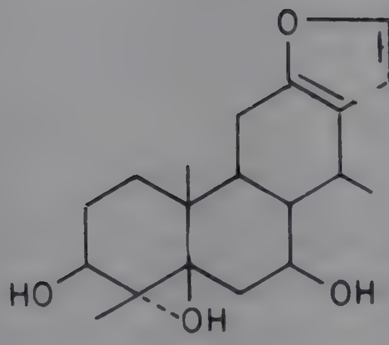

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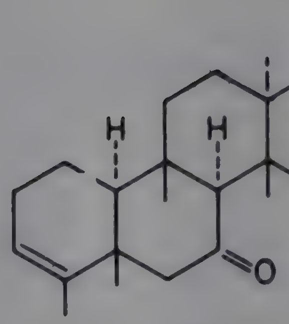

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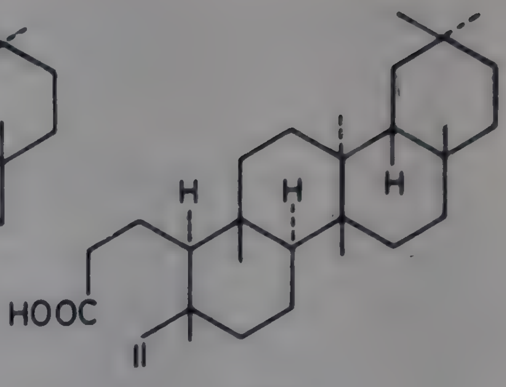

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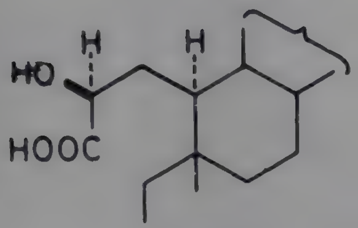

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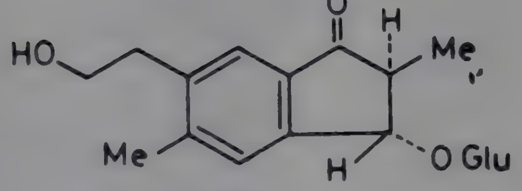

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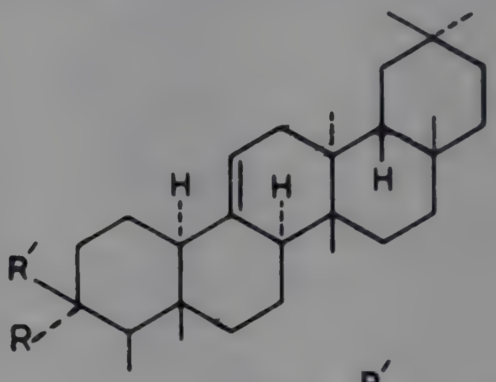

XV, $\underset{R}{\overset{R'}{>}}=O$

XVI, $R'=OH; R=H$

as (II), (iii) settled[3] the structure of psoralidin, a benzfuranocoumarin from *Psoralea corylifolia* Linn. as (III), (iv) isolated a new triterpenoid multiflorenol from the trunk bark of *Gelonium multiflorum* A. Juss and established[4] its structure as (IV), (v) isolated[5] the triterpenoid phyllanthol (V) from *Phyllanthus acidus* Skeels and discussed its biogenetic pathway, (vi) studied[6] the molecular rearrangements involving the triterpenoids glut-5-en-3β-ol (VI) and glut-5(10)-en-3β-ol(VII) and their 3α-epimers, (vii) isolated putranjivadione and roxburgholone from the bark of *Putranjiva roxburghii* and established their structures as (VIII)[7] and (IX)[8] respectively, (viii) isolated a new diterpene χ-caesalpin from *Caesalpinia pulcherrima* Swartz and suggested[9] structure (X) for it, (ix) studied[10] the molecular rearrangements involving 7-ketofriedel-3-ene(XI), (x) settled[11] the structure and stereochemistry of putranjivic acid (XII) and putranjic acid (XIII), (xi) studied[12] the molecular rearrangements of friedelan-3α, 4α-epoxide, (xii) devised[13], for the first time, a method for the functionalization of 25-methyl group of D : A-friedooleananes, (xiii) isolated wallichoside, a novel pteroside from *Pteris wallichiana* and established[14] its structure as (XIV), (xiv) studied[15] further molecular rearrangements of friendooleananes and made some important observations, and (xv) established[16] the structure and stereochemistry of the 25-nortriterpenoids putrone (XV) and putrol (XVI).

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A P B Sinha

Sinha's early work related to the synthesis of a series of new manganites of the general formula ($A^{2+}Mn^{3+}O_4$) and investigations on the process of cooperative Jahn-Teller effect in such solids. The experimental data collected on the crystal chemistry of these materials has been of great assistance in theoretical treatment of the basic processes involved in the crystal distortion and phase transformation of such solids. The order-disorder mechanism proposed by Sinha and collaborators for this type of transformation has been supported by various studies carried out abroad. In the following years, many groups all over the world have worked in this area and all the experimental results and conclusions drawn by Sinha have received wide support.

This family of manganites provided candidates with many new types of magnetic alignments. Ordering in several manganites with diamagnetic 'A' ion was studied with a view to getting an insight into the nature of B-B interactions in spinel structure. An interesting example of positive B-B interaction between Mn^{4+} and Mn^{4+} was observed. All other B-B interactions, namely Fe^{3+}-Fe^{3+}, Mn^{3+}-Mn^{3+}, Cr^{3+}-Cr^{3+}, etc. were known to be negative. The contrast between Mn^{4+} and Cr^{3+} was particularly noteworthy, because they are both iso-electronic (d^3). This highlighted the importance of direct exchange interaction in 90° geometry in preference to the well-known superexchange interaction, which dominates in 180° geometry. An interesting and unusual behaviour of temperature independent antiferromagnetism was observed in $ZnMn_2O_4$. A theoretical explanation of this behaviour was attempted using the molecular field approximation.

Copper manganite has indeed been a mysterious member of this manganite family. The cubic structure as against the tetragonal structure shown by all other 'normal-spinel' manganites, the unusually high electrical conductivity for an oxide and the positive B-B interaction have been solved by postulating a novel electron delocalization and transfer between Mn^{3+} and Cu^{2+} ions. Briefly, the results suggest a broad $d(e_g)$ band of copper overlapping with the narrow t_{2g} levels of Mn and the number of available electrons is such that it leaves 'holes' in the d band of $Cu(d^{10-x})$ to impart high conductivity and the corresponding Mn^{4+} ions generated remove the tetragonal distortion as well as give rise to positive B-B interaction.

With the availability of a large number of manganites and as a result of the ease with which they form solid solutions with other spinels (e.g. ferrites, chromites, cobaltites, etc.) it has been possible to tailor-make

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compounds having a wide range of electrical properties for applications as well as for understanding the mechanism of electron transport in such solids.

Attempt was made to explore the role of Jahn-Teller effect in the origin of ferroelectricity and it was found that it was indeed possible to get ordered phase in perovskite type structure leading to spontaneous polarization.

Sinha was one of the first persons to apply Mossbauer effect to solve some complicated structural problems in ferrites. Initially, reference compounds were so chosen that they had iron in a single valence state (Fe^{3+} or Fe^{2+}) and at a single site location. These reference spectra obtained have been unambiguous and characteristic of the valence state and the location of the ion and they have been used as an effective tool for studying more complicated distributions. In subsequent years, a large number of distribution problems have been solved using these data. A theoretical treatment has been developed for the temperature dependence of quadrupole splitting. Mössbauer spectroscopy also proved very useful in locating electron exchange processes in several mixed valence spinels.

During his work on CdS M-I-S junctions, a new type of switching and memory effect was observed and reported. The configuration remembers the direction of the applied voltage even after the voltage is switched off and can be erased by a light pulse or can be reversed by the application of voltage of opposite polarity.

While investigating the role of oxygen chemisorption in enhancing the dark conductivity of CdS photoconductors, Sinha succeeded in identifying the actual species formed through the application of photoelectron spectroscopy. The earlier conjectures were totally off the mark and it was indeed surprising that chemisorption of oxygen on CdS was stabilized through the formation of covalently bonded SO_4-like species. Indeed these studies led to the development of highly photoconducting films. The light to dark conductivity ratio is as high as 10^9.

Theoretical studies carried out on a new, potentially attractive solar cell configuration, viz metal-*p*-*n* Schottky barrier solar cells, have shown that the intervening '*p*' layer does indeed give a considerable improvement in the barrier height over the conventional Schottky barrier solar cells. The photovoltaic cell characteristics were worked out and conditions for maximum efficiency obtained. Extending this idea further, it was found that metal-*p*-*n* (hetero) Schottky promises even better results, as established by our theoretical investigations. This has opened up many possibilities and it would be interesting to explore them experimentally.

Sinha's explorations into new chemical routes for synthesizing useful electroceramics through novel precursors have given many interesting materials. These are in the area of superionic conductors, non-linear conductors and magneto-ceramics. Since the compounds are formed at temperatures much lower than those required in the conventional methods, the compounds are often non-crystalline and hence possess new properties. Sometimes, even new compounds have been discovered. All these offer possibilities of interesting new studies.

Surface and interface properties,

although widely realized to be very important, had often been neglected in solid state studies due to lack of suitable experimental techniques. With the advent of sophisticated techniques, such as photoelectron spectroscopy, it is now possible to investigate solid surfaces more quantitatively. During the last few years, Sinha has successfully established a school of activity attempting to study energetics, dynamics and chemistry in surface processes. Hopefully, this will lead to some understanding of the mechanism of chemical processes on solid surfaces.

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Sukh Dev

Nature has always fascinated man--artist, poet, scientist, philosopher—all! Thus, it is no wonder that in a country like ours, which abounds in botanical species, scented herbs and woods, and which has such a rich heritage of Ayurveda, the organic chemists often have a special fascination for the study of these products. This has been true for me as well, and since my major interest has been in this area, I shall restrict myself to an account of what I consider are our important contributions in the field of natural products chemistry.

Search for Exotic Molecules

For my Doctorate degree, I had worked (1945-1948) with Prof. P C Guha at the Indian Institute of Science, Bangalore, and this place had a long tradition of research in essential oils and terpenes. There I could see an impressive collection of oleoresins, resins, essential oils and terpenes, and this kindled in me a lasting interest in this area of natural products chemistry. Though work on certain woods, oleoresins and essential oils was initiated at the Indian Institute of Science, when I was a lecturer during 1953-1959, a much bigger and sustained research programme could be organized only at the National Chemical Laboratory,. Poona, where I had moved over by the end of 1959.

Classically, work on natural products had invariably been a difficult and time-consuming undertaking and many complex and novel molecules had resisted structure elucidation till 1950. However, with the introduction of modern spectroscopic methods, the situation started changing around 1950 and in the next one and a half to two decades it underwent complete metamorphosis. Structure determination then became vastly simplified and often routine. These developments affected the activity in this area in two ways. Firstly, more and more effort started being expended on biologically significant molecules, and secondly, a given raw material was now searched for new compounds as exhaustively as possible, so as to discover fundamental types in structures. Our efforts in these directions led to the discovery of several new structural types in terpenoids, as also the characterization of active principles of some biologically active materials.

The most important new fundamental structural types discovered by our group[1-4] are shown in Fig. 1. Below each compound is mentioned the botanical name of the plant and the part of the plant used for isolation. Invariably, these discoveries are examples of serendipity. However, in the case of longicyclene, the

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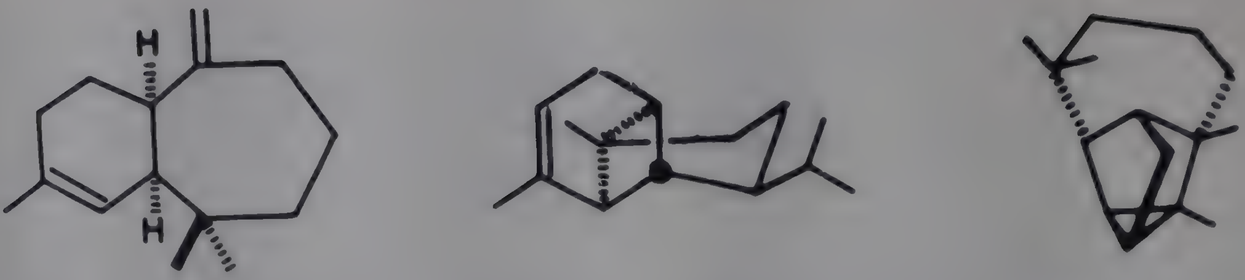
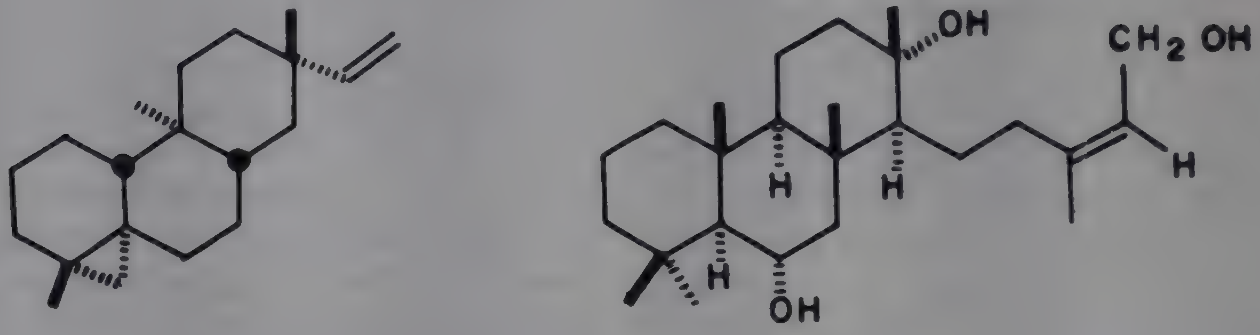


(-)-α-Himachalene
(Cedrus deodar, wood)

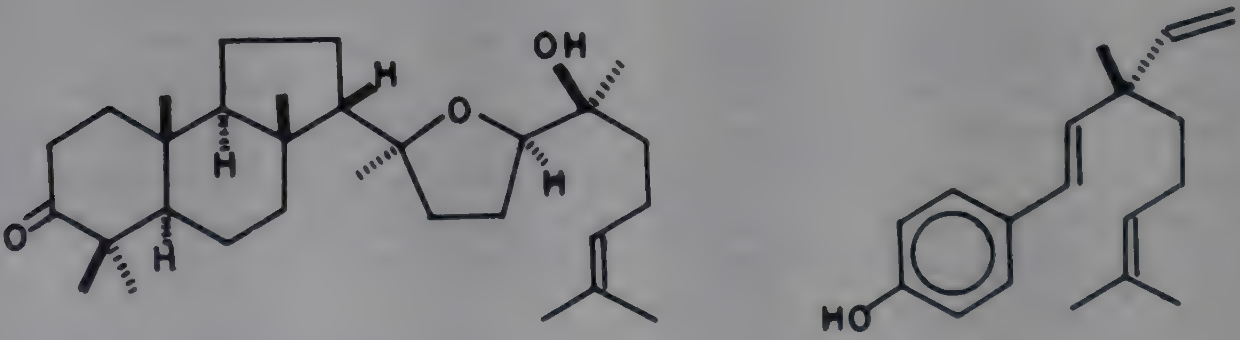
(-)-Copaene
(Cedrela toona, wood)

Longicyclene
(Pinus roxburghii, oleoresin)



(±)-Devadarene
(Erythroxylon monogynum, wood)

Cheilanthatriol
(Cheilanthes farinosa, whole plant)



Malabaricol
(Ailanthus malabarica, oleoresin)

(+)-Bakuchiol
(Psoralea corylifolia, seed)

Fig. 1—Some new structural types discovered

first tetracyclic sesquiterpene, we specially looked for such a molecule in the essential oil. In all these investigations, biogenetic concepts played a key role in structure elucidation[2]. These studies and similar studies by other groups have led us to propose two generalization:

(1) *Absolute Stereochemistry Biogenetic Rule*[2]: The absolute

stereochemistry of various constituents of a given class of chiral natural products in a given tissue must have the same (or derivable therefrom) absolute stereochemistry at a common reference point (unless each compound is formed by a one-step process, which is considered unlikely).

(2) Exotic biological materials tend to produce exotic secondary metabolites[5].

From the gum-resin of *Commiphora mukul* we were able to isolate a series of lipid tetrols (occurring as esters, e.g. C_{18}-guggultetrol ferulate, Fig. 2) which represent a new class of lipids[3], closely related to phytosphingosines.

Detailed investigations on lac, the insect resin elaborated by *Laccifor lacca*, finally led to the structure elucidation[6] of the main component of the 'hard resin' (Fig. 3).

Search for Biologically Active Molecules

Several Ayurvedic crude drugs have been investigated in an effort to isolate active principles. From Guggulu, the gum-resin of *Commiphora mukul*, two steroidal

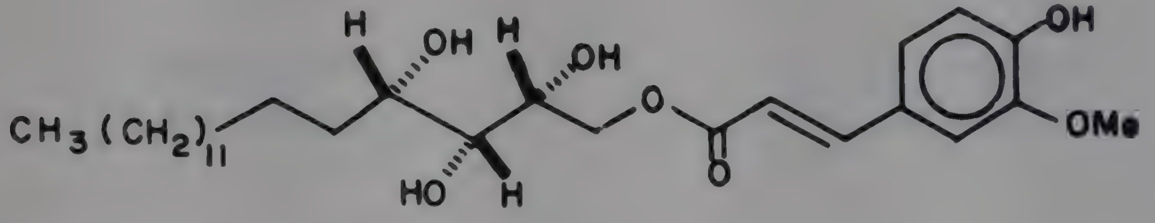
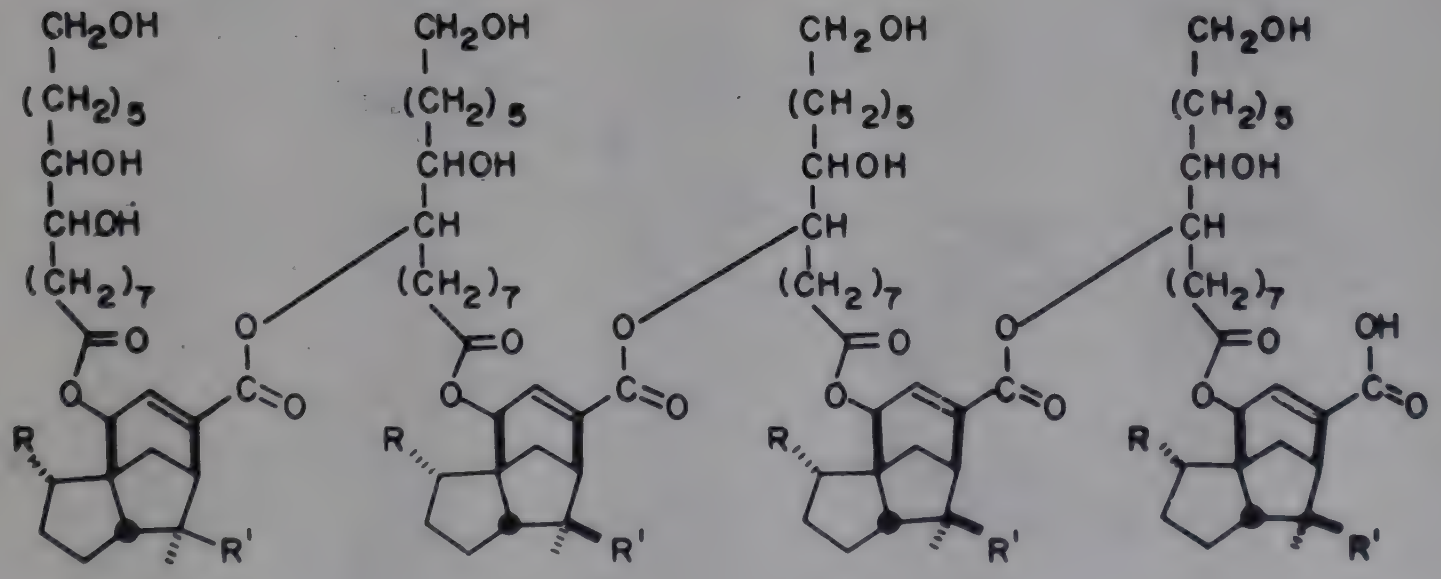


Fig. 2—C_{18}-Guggultetrol ferulate



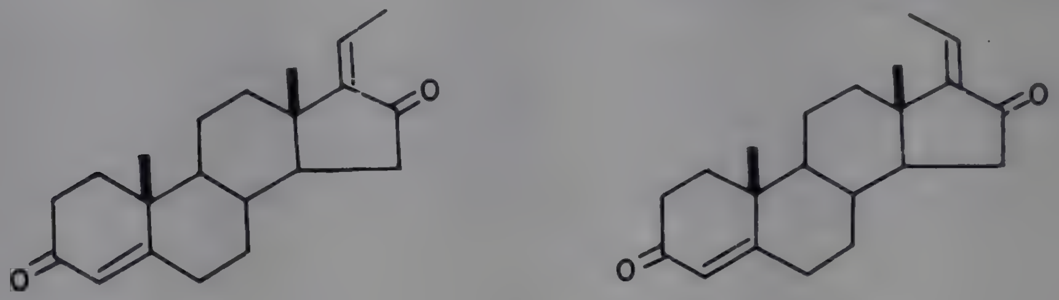
R=CHO/COOH

R'=CH$_2$OH/CH$_3$

Fig. 3—Structures of 'pure lac resin'

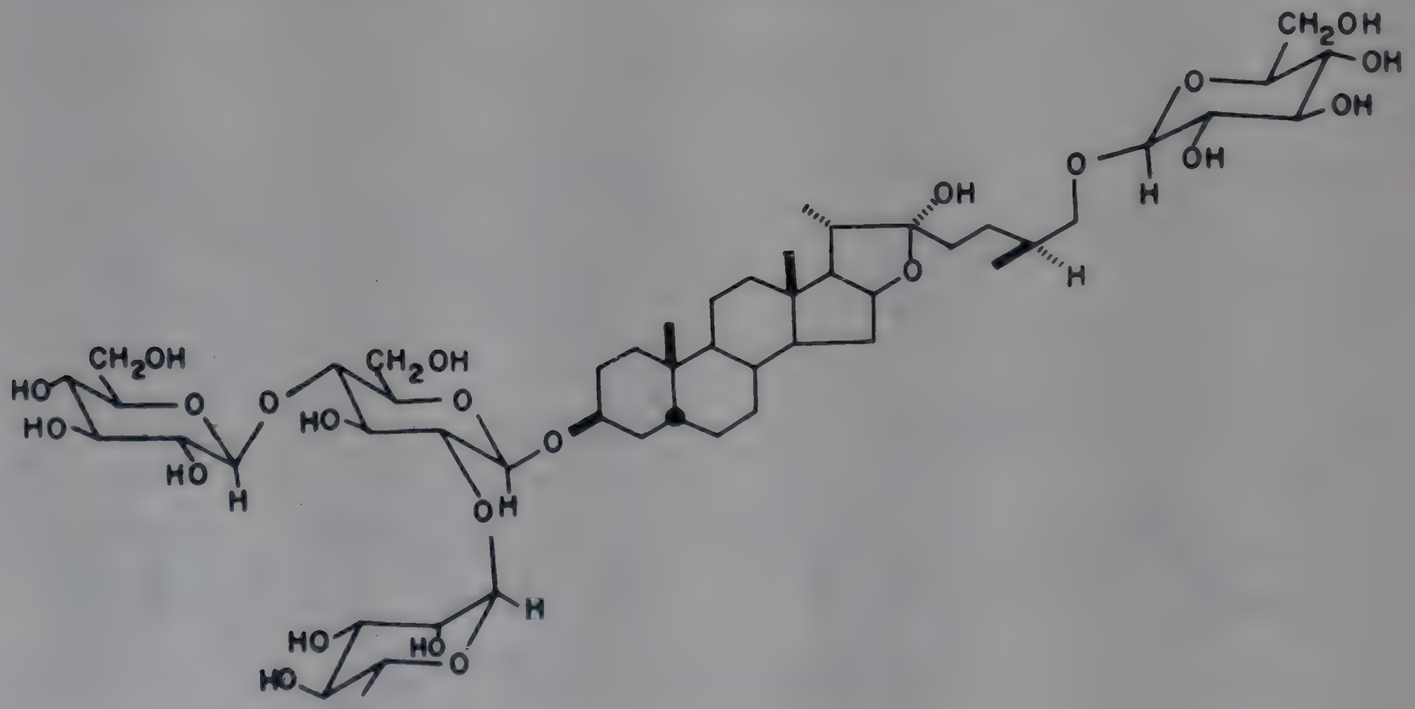
ketones *z*-guggulsterone and *E*-guggulsterone (Fig. 4), with pronounced hypocholesterolemic/hypolipaemic activity could be obtained[3,7]. Shatavarin-I (Fig. 4) was demonstrated as the anti-oxytocin principle of *Shatavari* (*Asparagus racemosus?*), a drug recommended in cases of threatened abortion[7] (also unpublished results). These results vindicated the ancient claims of Ayurveda. A modern hypolipaemic/hypocholesterolemic drug, based on *guggulu* is likely to be marketed in the near future.

Kodo millet (*Paspalum scrobiculatum*) is a minor grain crop of India, but has occasionally been reported to cause poisoning in man and animals when used



z-Guggulsterone
(Commiphora mukul)

E-Guggulsterone
(Commiphora mukul)



Shatavarin-I
(Asparagus racemosus?)

Fig. 4—Some biologically active molecules

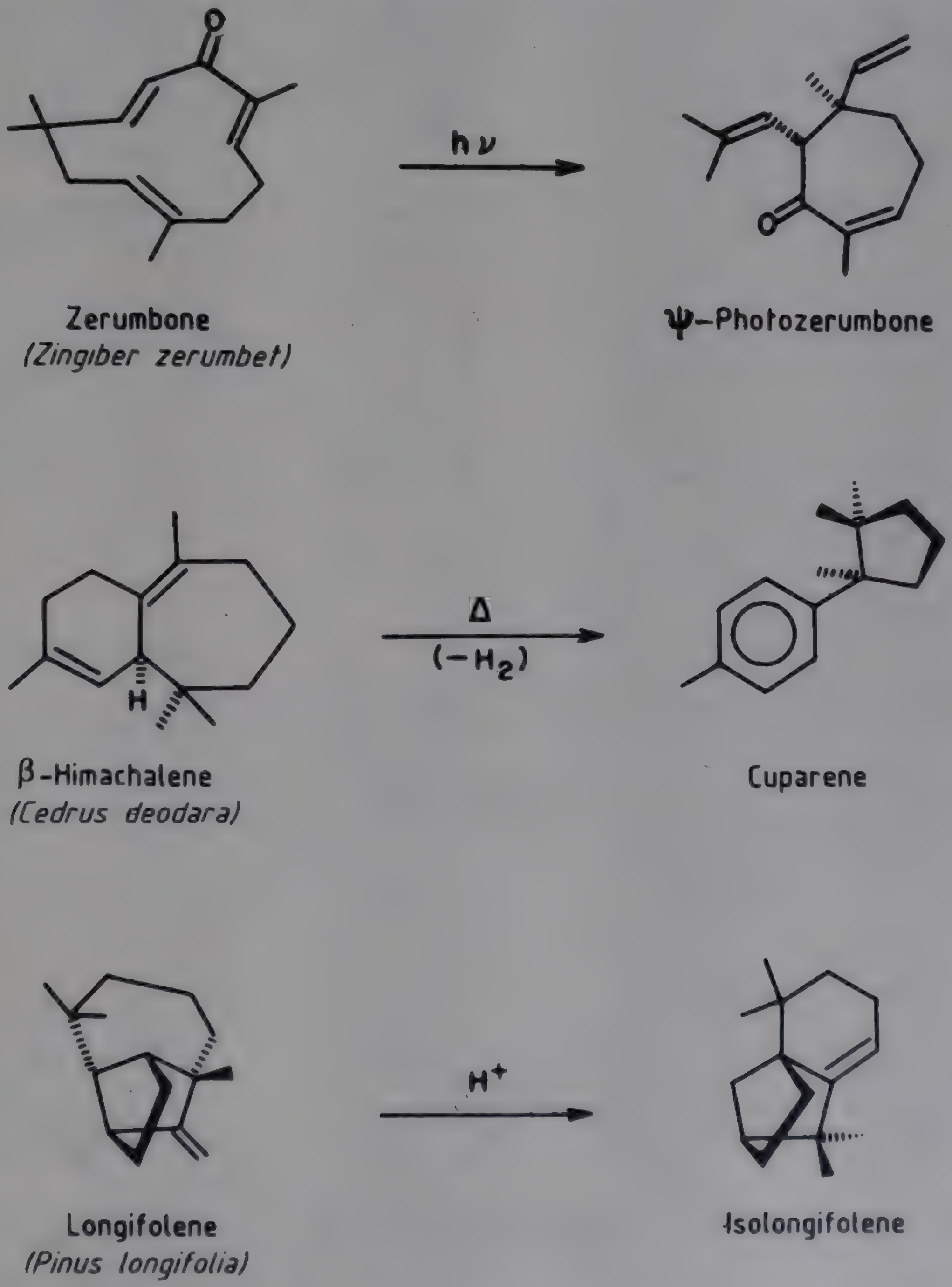
as food. It was demonstrated that the toxins are kodo-cytochalasins (Fig. 4), metabolites of fungus *Phomopsin paspalli*, a pathogen of kodo millet[8].

Tickling Molecules

Nature often produces molecules that are structurally strained or have such built-in stereoelectronic features that under slight provocation (chemical, photo, thermal) undergo reorganization. We encountered several such examples and Fig 5 summarizes three of these[9-11]. Rearrangement of longifolene to isolongifolene was investigated in great detail[9], as this transformation was of both academic and commercial interest. A number of perfumery materials based on isolongifolene are in the market in both India and abroad.

Restructuring Molecules

Abundantly available natural chiral



O
hν
Zerumbone
(Zingiber zerumbet)
Ψ-Photozerumbone
O
Δ
(−H2)
H
β-Himachalene
(Cedrus deodara)
Cuparene
H+
Longifolene
(Pinus longifolia)
Isolongifolene

Fig. 5—Rearrangement of molecules

compounds offer unique opportunities in restructuring them into more useful compounds, which are required in optically active form. Till recently, a major thrust of our research effort at Malti-Chem Research Centre, Baroda, where I had shifted in 1974, had been in this area. Specifically, economic routes have been developed for the conversion of the abundantly available (+)-car-3-ene (source: Indian turpentine oil) into several commercially valuable compounds (Fig. 6). (+)-Car-3-ene to (−)-menthol process has already been commercialized[3].

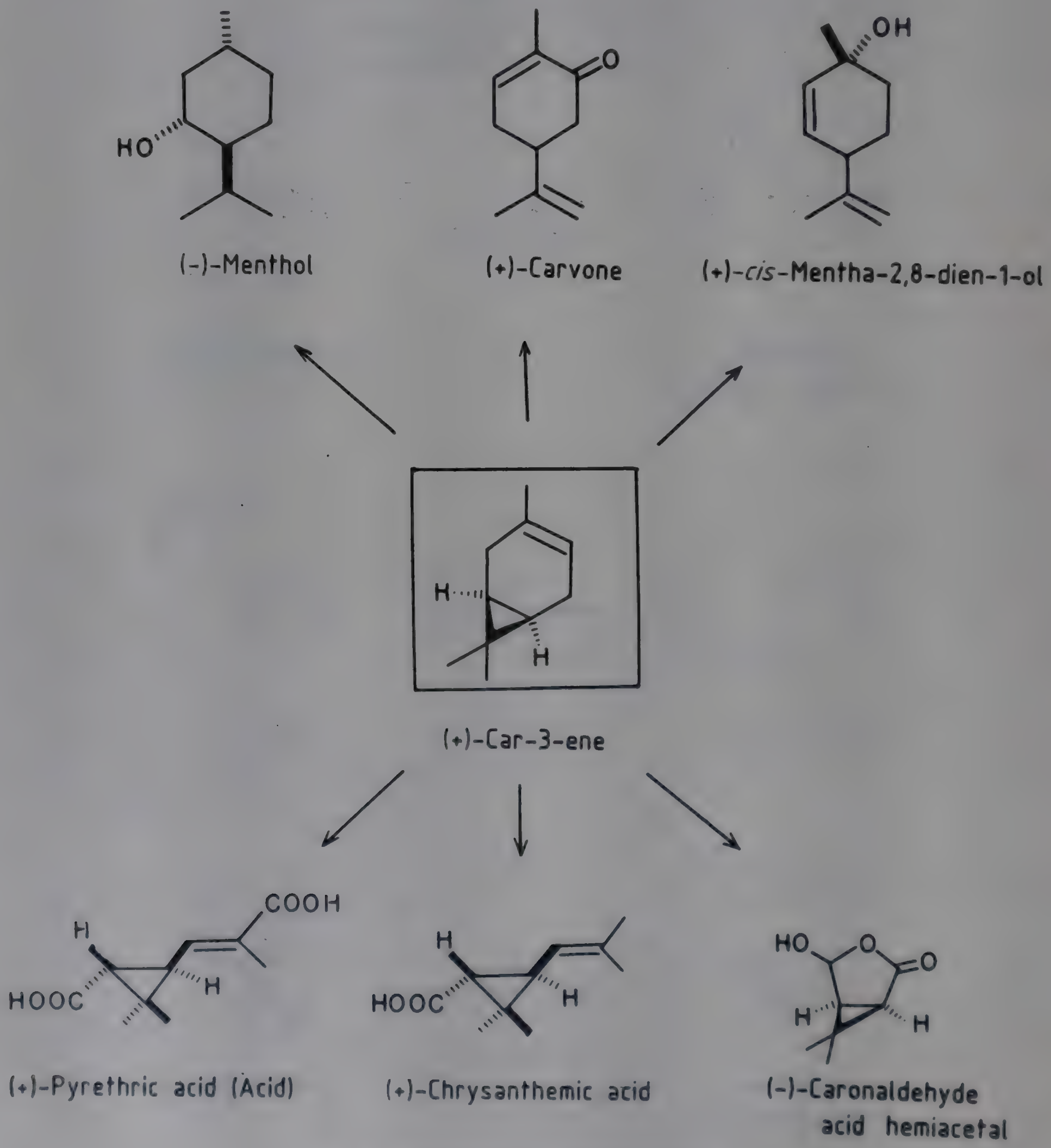

(-)-Menthol
(+)-Carvone
(+)-*cis*-Mentha-2,8-dien-1-ol
(+)-Car-3-ene
(+)-Pyrethric acid (Acid)
(+)-Chrysanthemic acid
(-)-Caronaldehyde acid hemiacetal
HO
OH
O
H
COOH
HOOC

Fig. 6—Restructuring of carene molecule

Cycloartenol is readily available from opium marc. In nature, cycloartenol plays a key role in the biosynthesis of *Buxus* alkaloids. In an effort to mimic some of these processes in the laboratory, we have carried out transformation of cycloartenol into a variety of *Buxus* alkaloids[12].

Epilogue

Natural product chemistry is a multifaceted splendour. Each one of the above areas is full of promise and challenge. We continue to explore these further, besides seeking to mimic the subtle pathways of nature.

Laboratory practice is the bed-rock of chemistry. One needs intelligent and dedicated students and colleagues to translate visions into reality. I had these in good measure. In the evening of my professional career, when I survey the canvas, spontaneous thanks go over to all of them.

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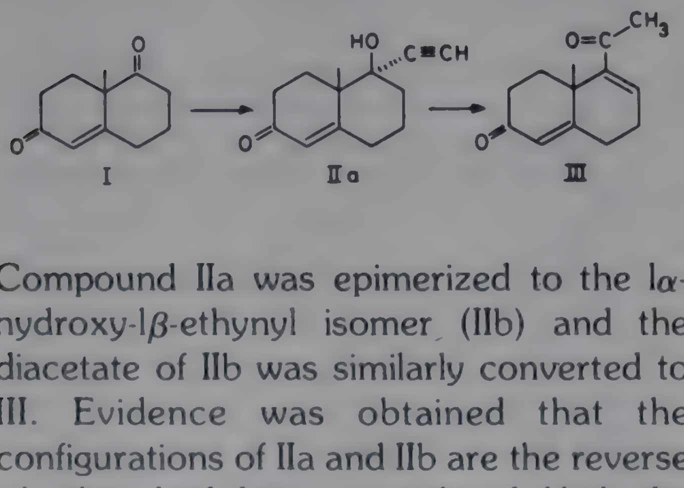
S Swaminathan

Swaminathan has made contributions in the following areas: (1) Synthetic approaches to non-aromatic steroids, (2) Molecular rearrangements, (3) Alicyclic chemistry, (4) Chemistry of indole and related heterocyclics, and (5) Stereochemistry of hindered benzophenones and related compounds.

(1) Synthetic Approaches to Non-aromatic Steroid

The main objective of the work in this area was to utilize 1,6-dioxo-8a-methyl-1,2,3,4,6,7,8,8a-octahydronaphthalene (I) as the starting material for the synthesis of non-aromatic steroids. This was elaborated to l-acetyl-6-oxo-8a-methyl-3,4,6,7,8,8a-hexahydronaphthalene(III) as follows[1]:



I IIa III

Compound IIa was epimerized to the lα-hydroxy-lβ-ethynyl isomer (IIb) and the diacetate of IIb was similarly converted to III. Evidence was obtained that the configurations of IIa and IIb are the reverse of what had been considered likely by other workers. New structures were established for two isomeric compounds previously assigned structure III. One of these—a crystalline compound—was shown to be a bicyclo-octane derivative formed by an unusual bridging of an acetylene function across the 1,4-carbon atoms of a cyclohexane ring.

Attempts to use compound I for building up steroidal rings C and D were unsuccessful due to its ready isomerization to a more conjugated diene dione whose structure was deduced on the basis of its spectral properties.

In other variations arrived at utilizing IIa and IIb, they were reduced to the corresponding vinyl alcohols IVa and IVb. In one of these variations, the vinyl alcohols IVa and IVb were sought to be dehydrated to the corresponding dienes. This attempted dehydration gave only rearranged products. In another approach, the acetylenic alcohol IIa was converted to an allene acetate by Isler reaction and then transformed in several steps to a *d*-homo-seco-trione. In other studies, the carbinol IVa was treated with 2-methyl-cyclopetane-1,3-dione under selected conditions to furnish a tetraketone which cyclized readily to a l-oxo-steroid[2].

(2) Molecular Rearrangements

Perhaps the most important contribution of Swaminathan and his group is the discovery in 1962 of a novel molecular rearrangement[3]. He has

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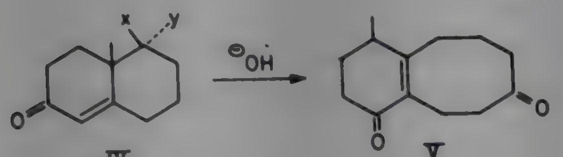
reviewed[4] contributions from his laboratories and from elsewhere in the above area up to 1983. The first report described the rearrangement of the vinyl alcohols IVa (and its epimer IVb) to the ring enlarged dione V when treated with a base.

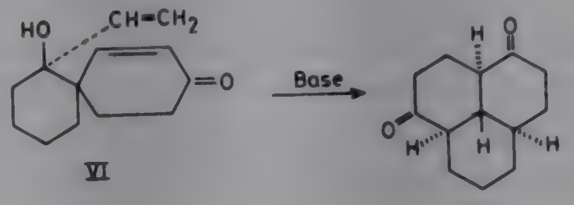


IV V

IV a, $X = OH,\ Y = -CH = CH_2$

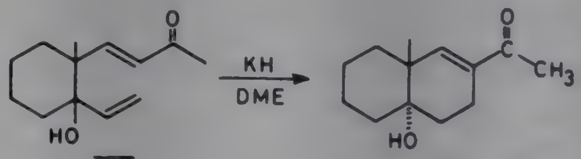
IV b, $X = -CH = CH_2\ Y = -OH$

The structure of V was confirmed by synthesis of the phenol obtained by its dehydrogenation. Several studies bearing on the scope of this rearrangement and also its mechanistic aspects have been carried out. Incidentally, the rearrangement of IVa to V is the first example reported in the literature of an anionic oxy-Cope rearrangement. Such anionic oxy-Cope rearrangements have come into great prominence since 1975 for the synthesis of diverse types of carbocyclic systems. From further studies of the rearrangement, Swaminathan has reported[5,6] that transannular interactions occur along with ring expansions. Such rearrangements involving transannular reactions have been confirmed by American workers and provide new potential routes to the synthesis of naturally occurring products containing an 8-atom ring. Transannular reactions of a similar type were also encountered[7] in metal/ammonia reduction of dione V and also during hydration of a methyl derivative of the carbinol IIa. In other studies of base catalysed rearrangement of oxy-Cope systems, Swaminathan and his colleagues have shown[8] that the spiro system VI rearranges to the perhydrophenalene dione VII in the presence of a base.



VI VII

They also worked out the synthesis of benzotropones based on the anionic oxy-Cope rearrangement. A novel synthesis[9] of *trans*-octalenones of the type IX by a base catalysed rearrangement of the oxy-Cope system VIII has also been reported by them.



VIII IX

They demonstrated[10] that the mechanism of the base catalyzed rearrangement of an oxy-Cope system can be either concerted or stepwise, depending on the solvent and the reagent used.

Incidental to the above studies, it was found that 2-bromocyclohexane-1,3-dione suffered ring contraction on treatment with organic bases. Swaminathan and his colleagues have made significant contributions to the chemistry of cyclic 1,3-ketones and also to the chemistry of acetylene compounds in the course of the above rearrangement studies. Their procedures for the preparation of 2-methylcyclopentan-1,3-dione, 2-methylcyclohexane-1,3-dione and 2-methylcycloheptane-1,3-dione are well documented. Robinson annelations of these diketones were found to yield both expected and unexpected products under different conditions. The carbinol IIa was found to undergo an interesting inversion of configuration on treatment with mercuric acetate to furnish the α-acetoxy hydrated product. In other studies on acetylenic compounds, Swaminathan and coworkers reinvestigated the Diels Alder reactions of acetylenic ketones with cyclopentadiene and showed that the adducts were dimers, the structures of which were determined. The photochemistry of these dimers has also been studied[11].

(3) Alicyclic Chemistry

With a view to extending the scope of the anionic oxy-Cope rearrangement, Swaminathan and coworkers synthesized a number of bicyclic diketones of potential use in the synthesis of natural products and new carbocyclic systems. Incidental to this synthesis, a reagent for facile 5-carbon annelation of a cyclonone was found[12]. The reactions of some of the above bicyclic diones with dimethyl oxo sulphonium methylide and the rearrangement of the products have been studied. The unusual reductive cyolization of metal-NH_3 reductions, leading to the formation of a 4-membered ring, has been reported[13] by Swaminathan in the case of the acetylenic alcohol IIa. Other studies in alicyclic chemistry included a facile 4-carbon annelation sequence involving a Wittig reaction, a one-pot synthesis of 2-alkyl cyclohexanones and some Diels-Alder reactions.

(4) Chemistry of Indole and Related Heterocyclics

Swaminathan and his group were the first to show[14] that contrary to the earlier belief, 3-substituted indoles undergo the Mannich reaction to give N-Mannich bases. In fact, they have shown that unsubstituted indole itself in the absence of acid reacts with formaldehyde and dimethylamine to give exclusively N-isogramine, which in the presence of acid isomerises readily to gramine. They have synthesized alpha-amino acids related to tryptophane, which may be expected to have interesting and biological properties.

In related work, they have developed[15] a new practical synthesis of thieno (2,3,b) and thieno (3,2,b) pyrrole systems.

In other studies, Swaminathan and collaborators have synthesized some 6-aryl-4-methoxy-alpha-pyrones, which are analogues of the naturally occurring marindenin and as such are potential tranquilizers. They have also worked out the syntheses of some fluoro-1,2-benzanthracenes in connection with cancer research. The reactions of indoline with Villsmeier reagent and also 2-phenyl-4-methoxymethylene-5-oxazolone have been shown to give N-substituted products rather than 5-substituted products, as reported previously. Indoles and indole Mannich bases have been shown to furnish indole-3-aldehydes when reacted with hexamine. They have reported improved synthesis of thieno (2,3-b) and (3,2-b) pyrroles involving (a) Wittig reactions, and (b) thermolysis of 2-azido vinyl thiophenes.

(5) Stereochemistry of Hindered Benzophenones and Related Compounds

Swaminathan's group has made a significant contribution in the field of stereochemistry also. They demonstrated[16] for the first time the existence of optical isomerism caused by steric interactions in a suitably substituted benzophenone.

Interest in the stereochemistry of similarly substituted diphenyl ethers led Swaminathan and coworkers to obtain evidence for the participation of an *ortho* substituted carbonyl group in aromatic nucleophilic substitution reactions. They found[17] that while methyl-2-chloro-3,5-dinitrobenzoate condenses with unhindered phenols in pyridine to give the normal products of displacement of chlorine, it condenses with hindered phenols to give aryl-3,5-dinitrosalicylates.

On the other hand, 2-chloro-3,5-dinitrobenzoic acid reacts with phenols and alcohols in pyridine to give exclusively aryl and alkyl-3,5-dinitrosalicylates. The formation of the aryl salicylates in both cases implicates the o-methoxy carbonyl and the o-carboxy groups, suggesting that β-lactones are intermediates in the observed acylations.

This was the first time that convincing chemical evidence was reported for the participation of a neighbouring group in aromatic nucleophilic substitution reactions.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M M Taqui Khan

Taqui Khan has made significant contributions in the fields of Homogeneous Catalysis and Coordination Chemistry. Novel ruthenium, rhodium and other platinum group metal complexes with mono[1,2] and polydentate[3,4] π-acidic ligands like phosphines, arsines, CO, NO were synthesized and activation of small molecules like O_2, H_2, N_2 and CO studied. Some of the Ru(II), Rh(I) and Ir(I) catalysts were proved to be very efficient catalysts in the homogeneous hydrogenation reaction under ambient conditions[5,6]. A salient feature of the work on homogeneous hydrogenation is the structure-reactivity correlation of the complexes of Rh(I) and Ir(II) with ligands with mixed hard and soft donor atoms[5–7]. The earlier contributions of Taqui Khan have resulted in the publication of a two-volume monograph on *Homogeneous Catalysis*[8] (Academic Press, 1974).

The most important contribution in the area of coordination chemistry is the synthesis of a new system of water soluble dioxygen complexes of ruthenium(IV) with aminopolycarboxylic acids as ligands[9,10] These complexes are both dibridged μ-peroxo-μ-hydroxo[9] and monobridged-μ-peroxo[10] type. These complexes represent the first stable dioxygen complexes of 4d transition elements in aqueous solution. Some of the dioxygen complexes of Ru(IV) with EDTA were found to be efficient catalysts in a number of oxidation reactions[11] like the oxidation of ascorbic acid, PPh_3, cyclohexene, cyclohexanol and allyl alcohol. A monograph on dioxygen complexes under the general heading *Recent Advances in Frontier Areas* is under publication (Plenum Publishing Corp, New York).

Taqui Khan has contributed significantly to bioinorganic chemistry. Extensive equilibrium and thermodynamic data on metal complexes of purine and pyrimidine bases, nucleosides and nucleotides obtained by him have been widely cited in the literature. One of the important contributions in this area is the measurement of the extent of stalking interaction[12,13] in purine and pyrimidine complexes in terms of $\triangle\triangle H$ and $\triangle\triangle S$ values.

An important contribution in the area of photocatalysis has been the development of semiconductor hematite system for the photodecomposition of water[14]. An important milestone in photocatalysis is the catalytic activity of ruthenium dioxygen complexes as a nonconsumable relay for the hole in the photodecomposition of water[15] by microcolloidal suspension of CdS loaded with Pt, Ir, Rh and RuO_2.

Another important achievement in the field of photocatalysis is the photoreduction of molecular nitrogen to ammonia at ambient conditions[16]. The

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system involves the irradiation of semiconductor colloids in aqueous solution of a dinitrogen complex. The semiconductor acts as light absorbing unit and the dinitrogen complex acts as electron acceptor as well as catalyst. The system produces ammonia with a turnover number (moles of ammonia/mole of catalyst) of about 100 under visible light irradiation and a current of nitrogen at ambient conditions.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

O P Vig

In the early years of his research career, Vig engaged himself in the synthesis of antimalarials[1] and polyaromatics[2]. He later switched over to the fascinating area of natural products synthesis, particularly that of terpenoids. These compounds are the oldest studied group of natural products and for long have been a challenge to the creative endeavours of synthetic organic chemists. Under a long-term programme, Vig and associates made notable contributions in synthetic organic chemistry. A number of new and convenient methods were developed and subtle applications made of some of the versatile reactions, such as Witting reaction, Horner-Wittig reaction, Claisen rearrangements, hydroboration-oxidation, hydrogenolysis by Birch reduction, nickel tetracarbonyl induced cyclizations and the reactions of B-keto sulphoxides, dianions and orthoester, Claisen migration, etc. Taking advantage of the afore-mentioned synthetic techniques, the syntheses of a large variety of terpenoids, including mono-, sesqui- and diterpenoids and other related compounds have been accomplished[3–10]. A mention of some of the elegant syntheses of terpenoids by Vig and his colleagues has been made in several review articles, periodicals and books on natural products.

Recently, Vig has started working on the syntheses of insect sex pheromones and juvenile hormones. This is largely because some of the members of these classes of compounds have a terpenoid framework and find use in pest control.

Vig's future plans include a systematic programme towards the synthesis, characterization and biological evaluation of insect sex-pheromones and juvenile hormone mimics. A number of research papers in this field have already been published[11].

Among the awards and honours won by Vig are U.G.C. Lecturership (1978-79), Acharya J C Ghosh Gold Medal (1979) and T R Govindachari 60th birthday award (1982). Vig spent two years in U.S.S.R. as a post-doctoral fellow (1958-60) and also attended the third Indo-Soviet Symposium on the Chemistry of Natural Products at Tashkent (1973). He was on a visitor-fellowship under the Indo-American fellowship programme to USA in 1979. More than 40 students have received their PhD degrees under his guidance.

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Sectional Committee—IV : Engineering & Technology

(Applied Physics, Chemical Technology, Electronics and Telecommunication, Engineering and Engineering Sciences)

K P Abraham

High temperature metal extraction processes, such as iron and steel making and copper smelting, have been developed over the years mostly on empirical basis. It was after the second world war that serious attempts were made to understand the physico-chemical principles underlying the high temperature metal extraction and refining processes. Beginning from the 1940s, much work was done by several research groups on the measurement of thermodynamic and kinetic data relevant to reacting systems encountered in high temperature extractive metallurgy. The research and development contributions reported here belong to this category.

The main areas of research and development work carried out can be identified under the following heads: (1) Measurement of thermodynamic properties of silicate melts by gas equilibration techniques and calorimetry, (2) Investigations on the thermodynamic properties of (a) binary metal oxide systems and (b) oxygen dissolved in copper alloys by the high temperature solid electrolyte galvanic cell technique, (3) Studies on the kinetics of gas solid reactions by thermogravimetric techniques, and (4) Development work on the electroslag refining of steels and non ferrous metals.

(1) Thermodynamic Properties of Silicate Melts

Abraham carried out research in this area in the 1950s as a member of the Nuffield Research Group in Extraction Metallurgy at Imperial College, London. The work carried out includes measurement of (a) MnO activities in binary and complex silicate melts at iron and steel making temperatures (1400-1700°C), and (b) sulphur holding capacities of silicate melts of interest in iron and steel making.

The thermodynamic activity of MnO in the melts was studied by equilibrating the melts with a gas phase of known oxygen potential and a Mn-Pt alloy of known Mn activity. The data collected[1,2] are useful in predicting the behaviour of manganese under a variety of iron and steel making conditions.

Sulphur is a deleterious element in steels and for a variety of applications, its concentration has to be brought down to very low limits and in some cases to parts per million levels. The sulphur holding capacities of a number of silicate melts were measured by equilibrating the melts with a gas phase of known oxygen and sulphur potentials and quantitative data[3] on conditions for transfer of sulphur to the slag were obtained.

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The thermodynamics of mixing of binary silicates when they formed ternary melts was studied by solution calorimetry; the result obtained showed that in the systems studied, the enthalpy contribution to the mixing process was negligibly small[4,5], in conformity with the theory of ideal mixing of silicate melts, according to which the only contribution to the free energy of mixing is the configurational entropy of mixing of the cations.

(2) Thermodynamic Measurements with High Temperature Solid Electrolyte Galvanic Cells

The early work on defect ionic crystals, particularly on stabilized zirconia and doped thoria, laid the foundation for a systematic study of solid electrolytes. By the late 1950s, it became known that these defect ionic crystals could be used as solid electrolytes in high temperature galvanic cells for the measurement of oxygen potentials and began to be used for a variety of applications. Studies were initiated in the Department of Metallurgy, Indian Institute of Science, Bangalore, to use this new technique for (a) measurement of metal oxide activities in oxide solid solutions, (b) evaluation of free energies of formation of oxide compounds, and (c) studying the influence of alloying elements on the thermodynamic activity of oxygen dissolved in liquid copper.

The properties of a number of binary oxide solid solutions were investigated by this technique, using lime, zirconia, thoria, yttria and calcium fluoride single crystals as solid electrolytes. These studies gave an understanding of the relative influence of ionic size disparity, electronegativity and crystal field stabilization effects (in the case of oxides of transition metals) on their mixing behaviour. The calcium fluoride single crystal solid electrolyte was also used for measuring the free energies of formation of a number of oxide compounds.

In the case of metal refining, one deals with impurities at low levels and the interaction between solutes at low concentrations in a solvent metal is of great significance. The Wagner interaction parameter, which is a measure of the interactions at low concentrations, is of value to the refiner. The effect of adding small quantities of cobalt, nickel, iron and manganese on oxygen dissolved in liquid copper was studied using this technique and the Wagner interaction parameters Σ_{o}^{Fe} and Σ_{o}^{Mn} were evaluated[8,9]

(3) Kinetics of Gas Solid Reactions

Roasting of metal sulphides in air, hydrogen reduction of metal oxides, chlorination and hydrochlorination are examples of metallurgically important gas solid reactions. Identification of the control mechanisms of these gas solid reactions is useful in the design of reactors. A few systems were identified for kinetic studies which were carried out by thermogravimetric techniques. A novel feature was the provision made for the simultaneous measurement of temperature changes occurring within the reacting solid. The studies have contributed to an understanding of the interplay of heat and mass transfer in controlling the reaction rates[10,11].

(4) Developmental Work on Electroslag Refining

Electroslag refining is a secondary remelting process designed for producing quality steels and alloys required for specialized applications needed by the nuclear, aerospace, power generation and aircraft industries. In this process, the commercially produced metal is refined with the help of a reactive slag kept molten by the ohmic heat generated when a heavy current passes through it. Though the process was developed abroad much earlier, it was only in the mid-sixties that work in this area was initiated in India. A laboratory scale electroslag refining unit was designed and constructed in the Metallurgy Department of the Indian Institute of Science, Bangalore, and based on the experience gained, a larger unit capable of producing steel ingots of 200 mm diameter was fabricated. The units were used to study the control mechanisms in the transfer of elements like manganese and chromium between the electrode and slag at the high operating temperatures (1500-2000°C). They were also used for collecting data on the slag compositions to be used for the refining of a variety of steels and nonferrous metals. Separate studies were made to assess the improvement in mechanical properties brought about by the remelting process[12,13]. The unit is being used for studies on the electroslag casting of intricate shapes.

A textbook on nonferrous extraction metallurgy[14] has been written with H S Ray and R Sridhar as coauthors.

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T R Anantharaman

Starting with his doctorate work at Oxford University in 1951 as the only Rhodes Scholar for that year from India, Anantharaman has been continuously engaged in metallurgical research for over three decades now, first as Post-Doctoral Fellow at the Max-Planck-Institut fuer Metallforschung, Stuttgart (1954-1956), then as Assistant Professor of Metallurgy at the Department of Metallurgy, Indian Institute of Science, Bangalore (1956-1962) and finally as Professor of Metallurgy at the Department of Metallurgical Engineering, Banaras Hindu University, Varanasi (1962-todate). He took active steps to establish a doctoral programme in an engineering discipline at Varanasi when technological research in general and metallurgical research in particular were still in their infancy in India and succeeded in due course in getting for his Department the recognition of "Centre of Advanced Study" from the University Grants Commission. To quote from the citation accompanying the conferment on him of the Distinguished Alumnus Award for 1982 by the Indian Institute of Science, Bangalore:

> "....Through his distinguished contributions to metallurgical education and research, by nurturing the Centre of Advanced Study in Physical and Mechanical Metallurgy at Varanasi and by inspiring generations of students, Professor Anantharaman has had profound influence on the growth of metallurgy in India. The primary credit for the outstanding profile of present day Indian metallurgical research rightly belongs to him."

While successfully upholding the dual responsibility of teaching and research in an academic institution, Anantharaman has been able to establish at the Department of Metallurgical Engineering, Banaras Hindu University, Varanasi, active schools of research in the following areas over the last two decades:

(1) Structural Imperfections in Metals and Alloys

(2) Structural Changes in Metals and Alloys

(3) Structure of Rapidly Solidified Alloys

He has published over 170 research papers and edited three books[1-3].

Structural Imperfections in Metals and Alloys

Since the last four decades, it has been generally accepted that structural imperfections like vacancies, dislocations and stacking faults, in spite of their small number in relation to the total volume of the solid, largely determine the mechanical behaviour of solid metals and alloys

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Among these types of defects, dislocations and stacking faults are amenable to study by the X-ray diffraction technique, as they affect X-ray reflections in several ways. Anantharaman and his coworkers have contributed significantly to the development of theoretical treatments for the X-ray diffraction effects of stacking faults as well as to their application for experimental evaluation of imperfections in several metals and alloys.

One of Anantharaman's early contributions in this field emerged from his doctorate work at Oxford and dealt with a new method for measuring integral breadths of X-ray reflections[4]. Subsequently, a general method of analysis for the separation of domain size, lattice strain and stacking fault contributions from X-ray breadths of face-centred cubic (fcc) metals was developed by his group[5]. Along with one of his students, he developed a modified Fourier method of analysis[6] using a single X-ray diffraction line to overcome the limitations of the well-known Warren-Averbach method, wherein multiple orders of X-ray reflections are required. From his doctorate work on cobalt he had earlier postulated for the first time that in hexagonal close-packed (hcp) crystals two types of stacking faults, viz., growth and deformation faults, could coexist[7].

Later, his group at Varanasi dealt with a third type of fault (extrinsic fault) in hcp structures and developed the necessary X-ray diffraction theory[8]. He also pointed out for the first time[9] that in the presence of particles of different sizes in cold-worked filings, asymmetry in peak displacements could occur in X-ray powder reflections due to different extent of deformation faulting in filings of different grain sizes.

An important theoretical development to the credit of the Varanasi group concerns possible fault configurations in double hexagonal close-packed (dhcp) crystals as well as the calculation of X-ray diffraction effects in such faulted structures[10]. A variety of plastically deformed metals and alloys and, for the first time, rapidly solidified alloys, were subjected to X-ray studies for imperfections by the Varanasi researchers and measurements of the stacking faults in them were carried out. Such X-ray studies on plastic deformation have encompassed a large number of pure metals with fcc, hcp and body-centred cubic (bcc) structures and alloys with fcc, hcp, dhcp and bcc structures. Notable in this respect is the award of the Kamani Gold Medal by the Indian Institute of Metals for his paper entitled "Structural irregularities in mechanically deformed cobalt"[11].

Structural Changes in Metals and Alloys

A knowledge of phase transformations in general and structural changes in the solid state in particular in different alloys is the foundation on which the modern science and technology of alloys development and processing has been built over the last five decades. The contributions of Anantharaman and his students in this field have revolved round the establishment of binary phase diagrams, the study of precipitation reaction in alloys and the investigation of tempering response in low-alloy steels.

At Varanasi, X-ray precision studies of copper-zinc alloys led to the exact determination of the solvus curve between the terminal fcc and the next bcc phases in that alloy system[12]. Among the binary phase diagrams, the manganese-gallium system is characterized by the combination of a very high melting metal with a very low melting metal. Anantharaman's work at Stuttgart during an extended visit in collaboration with German researchers led to the identification of eight peritectic, three eutectoidal and two peritectoidal reactions as well as ten intermetallic phases[13] in the Mn-Ga system. An explanation for the complexities in the electrical resistivity and superconductivity on annealing at sub-zero temperatures of alloys in the cadmium-mercury system, based on order-disorder transformations, was suggested[14] by him during a short visit to the San Diego campus of the University of California, USA.

Anantharaman has had an abiding interest in the study of precipitation hardening in aluminium alloys, partly because of the vast resources and potential for aluminium alloy development in this country. Extensive investigation of the precipitation reactions in aluminium-zinc alloys by his group led to a study of side bands[15] in their X-ray patterns and metastable solvus curves[16] in that binary system. Based on researches at the Imperial College, London, an explanation for the growth rate in the cellular reaction in Al-Zn alloys was offered by him[17], based on Turbull's theory of cellular reaction as controlled by cell boundary diffusion and influenced by continuous precipitation in the matrix.

Studies in Varanasi on the simultaneous effect of temperature and deformation on structural changes in commercial aluminium led to the identification of three temperature regions where ductility minima occur. These have been associated with the precipitation of Si, Al_3Fe and a metastable bcc Al-Si-Fe phase[18].

Structure of Rapidly Solidified Alloys

Rapid solidification of metals and alloys introduces several metastable effects in their constitution and structure, resulting in the development of unusual chemical, physical and mechanical properties in them. Though it has been known for a long time that the metastable state contributes to improvement in the mechanical properties of alloys, as in martensitic transformation and precipitation hardening, the potentialities of the metastable state could not be realized or exploited fully until the introduction of the 'gun' technique for rapid solidification by the late Prof. Pol Duwez at the California Institute of Technology, USA, in 1959. Following an extended visit to USA in 1965, Anantharaman pioneered research in this fast expanding new field in India. The contributions of the Varanasi group led by him have been in the areas of (a) development of techniques for rapid solidification[19], (b) estimation of cooling rates, (c) production of new non-equilibrium phases and determination of their crystal structures through X-ray and electron diffraction techniques, (d) study of micro-structure, (e) construction of metastable equilibrium diagrams, (f) theoretical postulation to predict the formation of metastable phases, and (g) production and characterization of metallic glasses. One of the earliest and most comprehensive reviews in this areas was prepared by him and one of his doctorate students in 1971 under the title "A Decade of Quenching from the Melt"[20]. About 25 new metastable phases have so far been discovered in Varanasi in rapidly solidified alloys and their crystal structures determined by X-ray and electron diffraction techniques. Anantharaman's

Presidential Address to the Indian Institute of Metals in 1978[21], and his Bhatnagar Medal Acceptance Lecture to the Indian National Science Academy in 1983[22] dealt with products of rapid solidification.

In recognition of his contribution in the area of rapid solidification, the Department of Science and Technology, Government of India, invited him to submit a proposal for the development of the production technology for amorphous metallic ribbons. As part of a National Project on Metallic Glasses, a Unit on Metallic Glasses was thus set up at Varanasi in 1982. Anantharaman and his coworkers have successfully developed the production technology for iron-base alloy amorphous ribbons of up to 5 cm width in this Unit. One of the very few books on metallic glasses[2] also emerged from these efforts.

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D P Antia

My first experience in research was in 1938 when I had to do a project as part of my bachelor's degree in metallurgy at Banaras Hindu University. I worked on improving the fluidity of type-setting alloys which included devising a method and designing and fabrication of an instrument for measurement of fluidity of liquid metals. I also experimented with some new alloys to improve fluidity.

After two years in industry as metallurgist to Godrej and Boyce Manufacturing Company, I joined Massachusetts Institute of Technology (MIT), Cambridge, Mass., USA, in 1940 and became a Research Assistant there in Physical Metallurgy. My research work was essentially on kinetics of heat treatment of different types of steels. In the thirties and early forties, the phenomenon of transformation of retained austenite in steels was not understood properly and most of the heat treatment was done on empirical basis. It was realized early by Prof. Cohen at MIT and others that the key to the proper understanding of the heat treatment of steels of different compositions depended on the quantity of austenite retained during quenching (i.e. the rate of cooling) and the transformation of the retained austenite in the solid state on subsequent treatment at different temperatures and times, which is termed tempering.

Although work was done previously on transformation of austenite at various subcritical temperatures, no systematic studies were made as to the quantities of austenite retained at different rates of cooling or on subsequent tempering at different temperatures for different times and the structure-property relationships resulting therefrom. The first problem, therefore, was to devise a reliable method for quantitative determination of the austenite retained on quenching from the upper critical temperatures before further work could be undertaken on its transformation in the solid state. After a great deal of experimentation, an X-ray method was devised which depended on the intensity of the diffraction patterns of the austenite in the samples. The intensity of the lines was measured with an electrophotometer. This method was checked by the laborious process of measuring areas representing austenite from microphotographs of the same samples. The X-ray method proved reliable and was adopted as a standard method for the determination of retained austenite.

High carbon as well as nickel and nickel-molybdenum steels were investigated upon with the general aim of studying the changes in microstructures and properties at various tempering temperatures. Several methods, based on

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study of X-ray diffraction, magnetic changes, microstructural changes and hardness variations were applied to the same samples to follow the changes taking place both during heating up to certain temperatures and cooling from these temperatures.

Unlike the situation obtaining in today's laboratories, no readymade instruments were available. We had to devise our own instruments to measure the different properties. Even the cameras for taking X-ray diffraction pictures had to be made in the workshop. Therefore, manufacturing instruments for measuring magnetic properties, hardness at high temperatures, etc., also became a part of the research work. We had also to make our own steels for experimental uses as we wanted proper control on the compositions of the steels studied.

As a result of the studies made on tempering of steels, a better understanding was obtained of what was happening to retained austenite during its transformation and its behaviour during tempering on structure-property relationship.

Other research work at MIT included study of various platinum and platinum-rhodium group of alloys as part of war-time research. Work was also carried out on high temperature hardness testing of various alloy steels. A study was conducted on cemented carbides for making cutting tools manufactured by powder metallurgy methods and using diamond impregnated carbide tools.

The American Society for Metals jointly awarded the Henry Marion Howe Medal for 1945 to Antia and his coworkers, S G Fletcher and Morris Cohen for their pioneering work on the tempering of high carbon steels.

Early in 1943, I joined the Aluminium Company of Canada after obtaining my doctorate degree from MIT in Physical Metallurgy and Mineral Economics. I was sent out to India in 1944 to set up a special plant for the manufacture of age hardenable aluminium alloys for aircraft manufacture and a laboratory attached to the plant.

At that time there was hardly any research work being done in India on metallurgical problems, nor were any reference libraries available. Any serious research was, therefore, not possible and therefore I had to concentrate on technological and development problems. The Council of Scientific and Industrial Research was established in 1942 to help in the war effort. Also, as part of India's post-war reconstruction plan, the Government of India had invited Prof. A V Hill in 1943 for discussions on the reorganization of scientific and industrial research. This led to the formation of several planning committees under the Department of Planning and in 1945 I was appointed part-time Secretary to the Metal Industries Panel and also member of the Metals Committee. The report of the Panel was mostly directed towards both rehabilitation and growth of non-ferrous metals industries after the war, including primary metal manufacturing industries like aluminium, copper, zinc, lead, etc, and their fabricated products. In 1946, I was appointed Director and Controller of Metals in the Directorate General of Munitions Production at Calcutta and later as Director and Development Officer in the Ministry of Supplies & Disposals at Delhi. Here, I was responsible for guiding government policy and advising on the manufacture of various metals, including steel and other non-ferrous metals.

In October 1950, I joined as representative of the British Aluminium Company in India and also as Director of Aluminium Manufacturing Company Ltd, Aluminium Hindustan Ltd, and A.P.V. Engineering Company Ltd. In this capacity, I introduced the use of aluminium and its alloys in various industries, such as rail, road and marine transportation, jute and cotton mills, automobiles manufacture, dairy and chemical equipment, etc. The work on Metals Committee continued and led to the establishment of the National Metallurgical Laboratory.

Since no metallurgical or materials science research was being carried out in India in the forties, nor was there a metallurgical reference library available for general use, I established and organized the Indian Institute of Metals in 1947 to promote the science and art of making, shaping and treating of metals and alloys. This is a major international professional body with over 6,000 members.

From 1955 as General Manager and Director of Union Carbide India Limited and later as its Deputy Managing Director, I was in complete charge of planning, implementing and operating all their new projects. I introduced impact extrusion of zinc and aluminium for the first time in India in Union Carbide plants. I also carried out research along with my colleagues on nucleation and grain refinement of zinc alloys leading to the manufacture of photoengraver and addressograph plates for the first time in India. Continuous research and development work was necessary on various aspects of manufacturing activities of Union Carbide, including the use of indigenous manganese for dry battery manufacture and introduction of new and improved types of dry batteries for military and civilian use. Electrolytic manganese dioxide and arc carbons were produced for the first time in India under my guidance.

I also took an active part in the standardization of metals and alloys and for many years helped the Indian Standards Institution in various standardization activities.

Since there are 103 elements, the possible number of binary alloys will be about 5000, while the number of ternary systems can be as large as 160,000. All systems are not equally important; when one realizes that alloys generally consist of more than six to ten elements, some in trace quantities, which may have profound effect on the structure and properties of alloys, the number of systems to be studied becomes enormous. The work of developing such phase diagrams therefore cannot be done in one laboratory or in one country. Therefore, the American Society for Metals and the National Bureau of Standards of USA decided in 1978 to organize an international programme to evaluate phase diagrams and the technical information relating to them. In 1981, I persuaded the Indian Institute of Metals to join this international programme, which formed a national committee under my chairmanship. The work involved not only persuading Indian scientists and laboratories to work on this programme but also to raise funds to do the work including worldwide literature survey, translations from foreign languages, evaluation, experimentation, thermodynamic studies and generally to assess, formulate, critically review and get the phase diagram work published. With the help and cooperation of many government ministries and departments, including Defence, Steel, Mines and Education, Department of Science and Technology, Defence Research and Development Organization, Tata Iron & Steel Co., etc., and some private sector assistance in funding, the work is now going on for the last two years on three binary and five ternary alloy systems in four I.I.T.s, BARC, DMRL, SAIL and TISCO laboratories. I coordinate all the work, get it reviewed internationally and published either in the *Transactions of the Indian Institute of Metals* or the *Alloy Phase Diagram Bulletin* of ASM. The work is ongoing and very vast in scope and dimensions. It will benefit not only our aerospace, electronics, nuclear and other existing industries but India will get the benefit of similar work done in a large number of other countries. It will take a long time to complete this work and shall keep me busy for many years.

Another research work I want to promote is related to 'Materials by design' which would involve measurement of free energy of the grain boundaries of metals

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A S Arya

The essential steps in a scientific approach to the design of engineering structures for resisting safely the imposed seismic ground motions are: (i) a realistic estimation of the ground motion parameters, viz. the earthquake magnitude, its focal depth and epicentral distance, and the intervening soil medium, using which a probable accelerogram is to be worked out in a given design life period at the base of the structure, and (ii) a dynamic response analysis of the structure which should take into account its mass and stiffness distributions, inelastic load-deformation characteristics, energy dissipation through structural and geometric damping, and influence of damage of non-structural elements.

Historically, structural design for earthquakes was started by representing the seismic effect by a lateral force proportional to the weight of the structure applied to it externally like the wind force. The seismic force was taken rather arbitrarily as 1/20th to 1/10th of the weight of the structure. The science of treating the earthquake effects on the basis of the dynamic response of the structure to the ground motion developed in the fifties and thereafter. Arya's research work was mostly in the area of rational seismic response determination and introducing innovations either for increasing the earthquake resistance of structures or reducing the seismic effects themselves. A brief account of his major achievements is given here.

Seismic Response Analyses

A number of tall structures, namely, chimney stacks, prilling towers, refinery column structures of mixed composition consisting of steel columns and reinforced concrete supporting structures, hyperbolic cooling towers, tall girder bridges, etc. have been analysed rationally by developing an appropriate transfer function type numerical analysis, introducing soil-structure interaction in the Timoshenko beam model wherein shear deformation as well as rotary inertia terms were also included[1–5]. Two examples of these are given below.

Effects of face slopes of gravity dams on their response[1] : Fig. 1 shows the dam sections, the stick model and the final results obtained from the parametric study, using $H = 100$, 150 and 200 m, $H_1 = 95$, 144, 193 m, and $B_1 = 8$, 8, 10 m, respectively; upstream slopes = 0, 0.0625 downstream slopes 0.6, 0.7, 0.75, 0.8, 0.85; and reservoir in full and empty conditions. The guidelines for the response calculations of dams were arrived at as follows:

Fundamental period $(T) = 5.55\ (H^2/B)\sqrt{\rho/E}$

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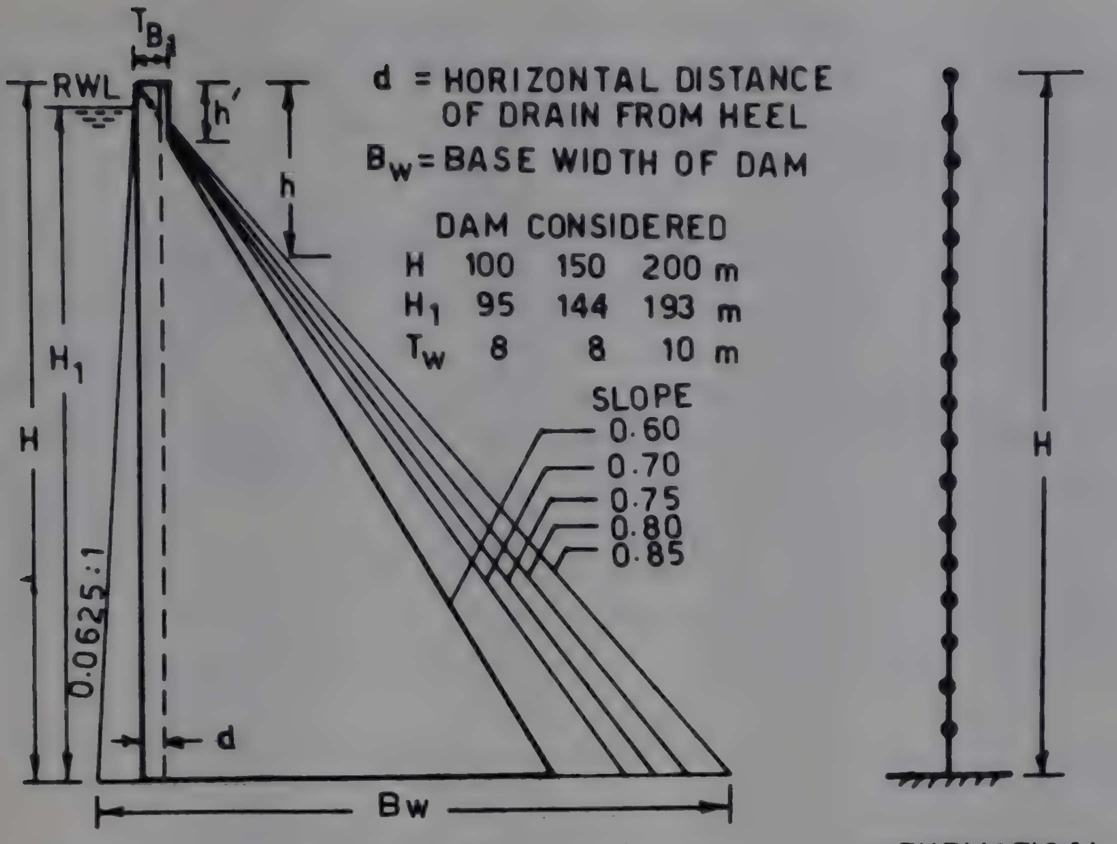
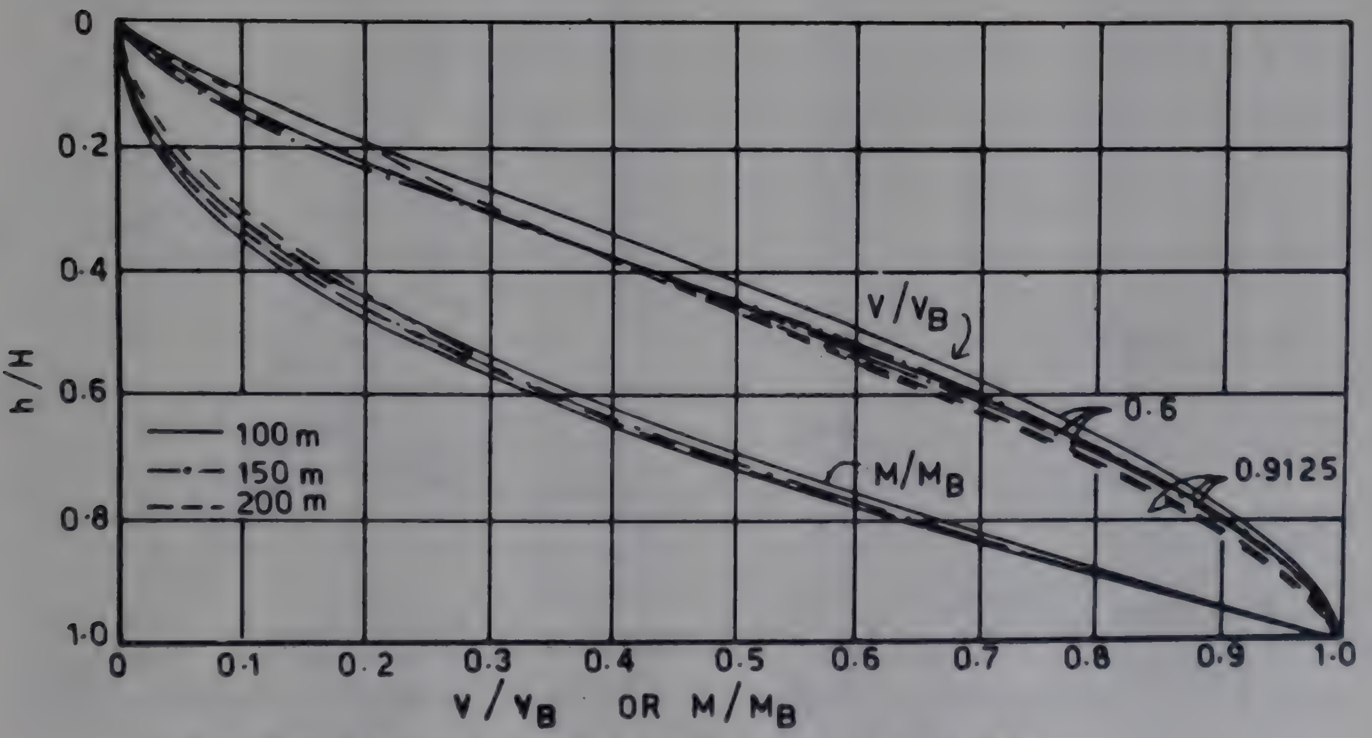

T_{B1}
RWL
h'
h
H
H1
0.0625:1
d
Bw
d = HORIZONTAL DISTANCE OF DRAIN FROM HEEL
Bw = BASE WIDTH OF DAM
DAM CONSIDERED
H 100 150 200 m
H1 95 144 193 m
Tw 8 8 10 m
SLOPE
0.60
0.70
0.75
0.80
0.85
H

(a) DAM SLOPES (b) MATHEMATICAL MODEL



(c) DISTRIBUTION OF V AND M ALONG HEIGHT

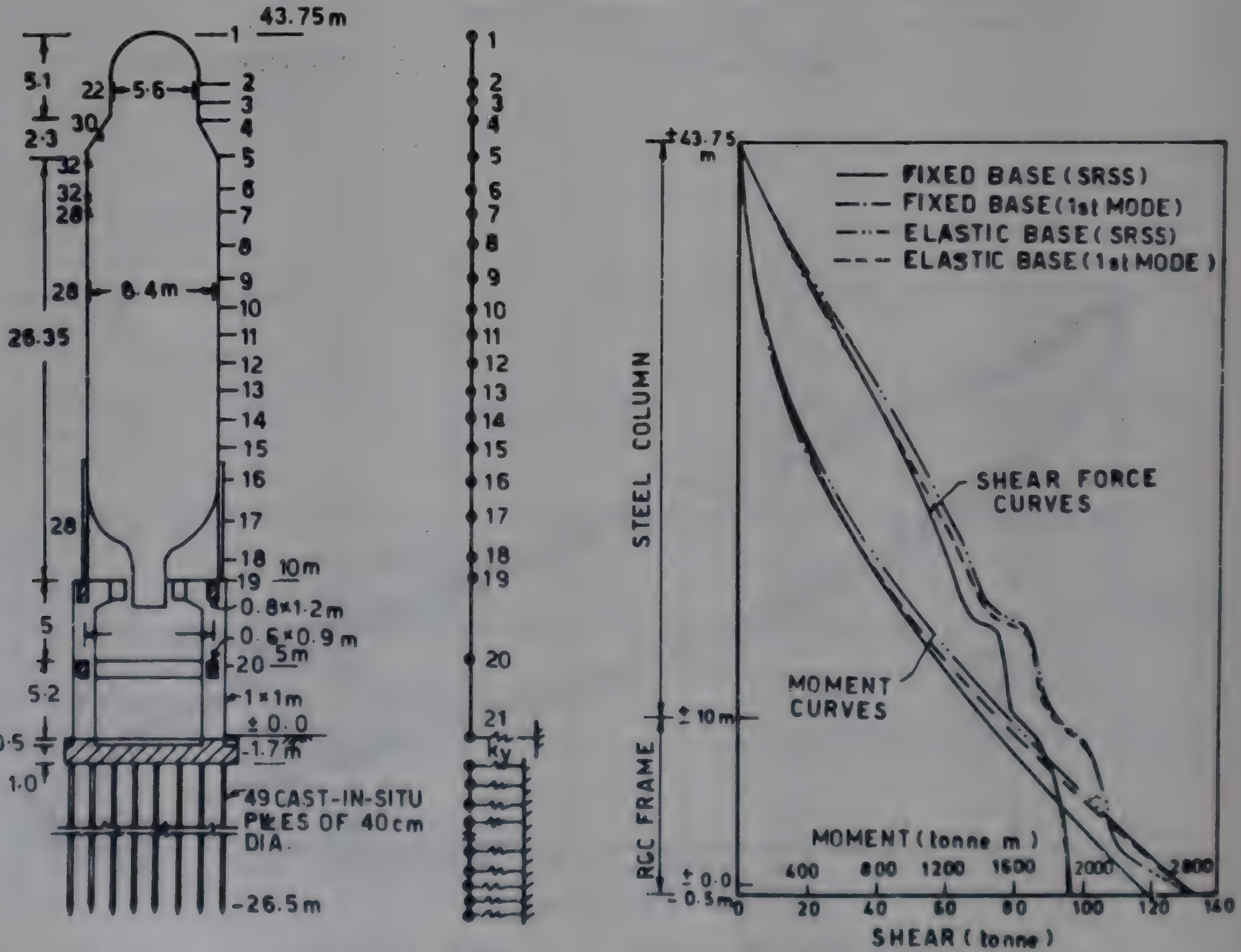
Fig. 1—Seismic response of concrete dams

where ρ is the mass density; and E, the modulus of elasticity of the dam material.

Base shear $(V_B) = 0.6\ W\alpha_h$; and Base moment $(M_B) = 0.6\ W\alpha_h\bar{h}$

where W is the total weight of dam; α_h, spectral acceleration for period T and appropriate damping, and $\bar{h}$, height of centre of gravity of the dam above the base. For any horizontal section at a depth h below the top, the seismic shears and moments may be obtained as a ratio of V_B and M_B using Fig. 1c. These results have been incorporated in Indian Standards IS : 1893-1975 for design of dams.

Response of tall refinery column structures resting on pile foundation[3] : The structure, its mathematical model, the mathematical model for the pile and the results obtained are shown in Fig. 2. The base spring of the superstructure, k_y, was obtained by considering the elasticity of the pile soil system, with piles as continuous elements. Piles have been modelled separately, as shown in Fig. 2 using similar analysis. From Fig. 2, the response is seen to be higher for the elastic base as compared with fixed base case, bringing out the importance of soil in the structural response.


43.75m
5.1
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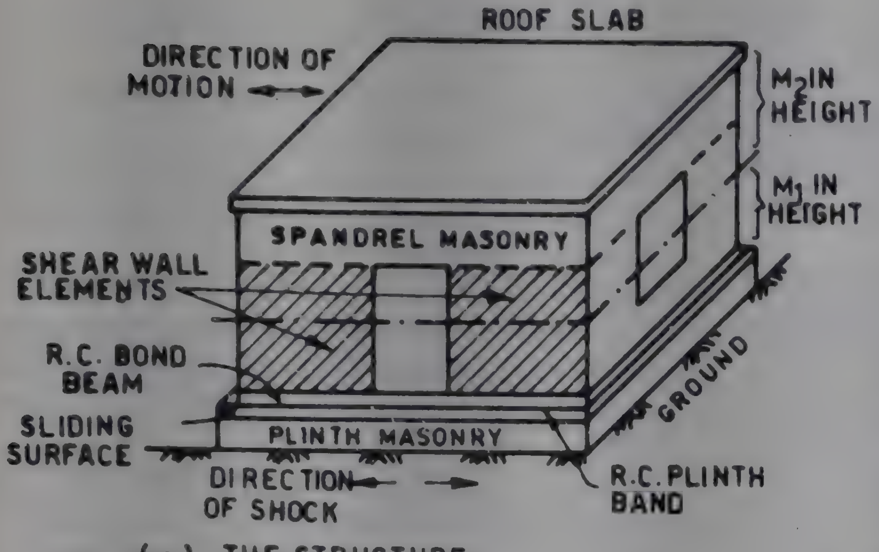
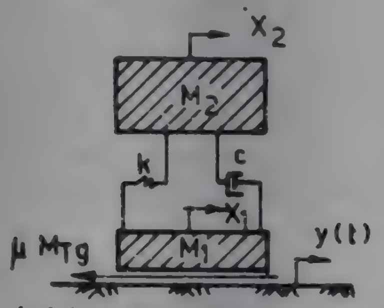
10m
0.8×1.2m
0.6×0.9m
20
5m
1×1m
± 0.0
-1.7m
49 CAST-IN-SITU PILES OF 40cm DIA.
-26.5m
21
ky
43.75 m
STEEL COLUMN
RCC FRAME
± 10m
± 0.0
-0.5m
FIXED BASE (SRSS)
FIXED BASE (1st MODE)
ELASTIC BASE (SRSS)
ELASTIC BASE (1st MODE)
SHEAR FORCE CURVES
MOMENT CURVES
MOMENT (tonne m)
400
800
1200
1600
2000
2800
0
20
40
60
80
100
120
140
SHEAR (tonne)

(a) STRUCTURE (b) MATH. MODEL (c) SEISMIC RESPONSE

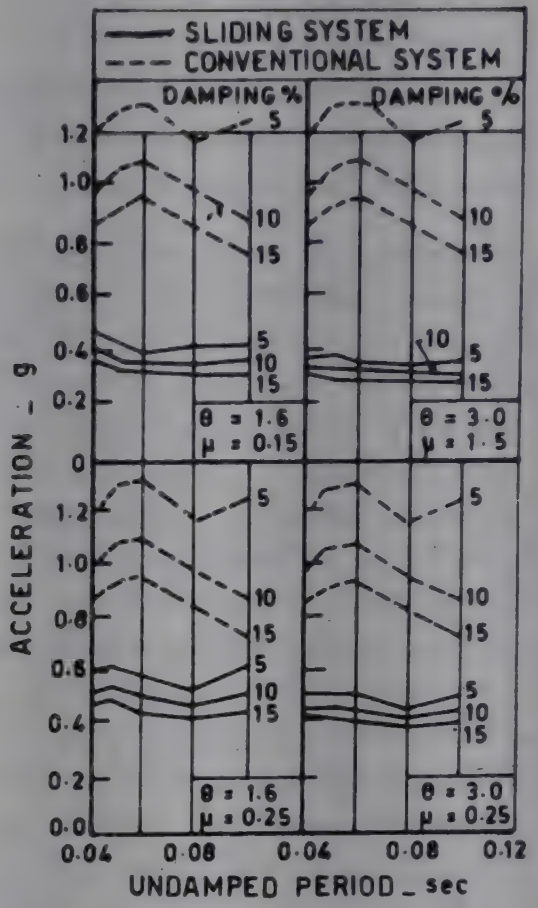
Fig. 2—Seismic response of refiner column structures


ROOF SLAB
DIRECTION OF MOTION
M_2 IN HEIGHT
M_1 IN HEIGHT
SPANDREL MASONRY
SHEAR WALL ELEMENTS
R.C. BOND BEAM
SLIDING SURFACE
PLINTH MASONRY
GROUND
DIRECTION OF SHOCK
R.C. PLINTH BAND

(a) THE STRUCTURE


X_2
M_2
k
c
X_1
$\mu M_T g$
M_1
y(t)

(b) MATHEMATICAL MODEL



(c) RESPONSE SPECTRA FOR KOYNA EARTHQUAKE

Fig. 3—Sliding concept for masonry buildings

Innovative Structural Systems

Detailed study of earthquake effects on sliding and overturning of freely supported objects during Koyna earthquake of 11 December 1967 and Broach earthquake of 23 March 1970[6,7] provided a novel approach to obtain strong ground motion data; it also gave an understanding of friction-supported structures[8–12] which has been used by Arya in developing new systems of safe and economical structural design. Two examples of masonry buildings are cited here.

Base isolation of brick buildings[8,9] : It was recognized that if the structure is isolated from the foundation through some isolation devices or if a flexible elastic system is introduced between them, the resulting seismic response of the structure is very much reduced. This concept is applied to brick and stone buildings by introducing a break in the masonry bonding and giving a relatively smooth level surface at plinth level. The resistance to sliding against ordinary lateral loads like wind and small earthquakes comes from the frictional resistance, but under large earthquakes, the superstructure is free to slide. Non-linear frictional resistance analyses to severe recorded accelerograms as well as shock-table tests of half-size specimens of one room masonry houses on shake table have clearly proved that the system is most efficient when it is most needed, i.e. when the peak ground acceleration coefficient is much larger than the coefficient of friction. Fig. 3 shows the system and some of the results. The frictional response spectra become flat and much below the elastic response spectra. Yet, the largest lateral sliding movement is estimated[9] to remain less than 25 mm.

Half-brick bearing wall construction[3] : Another scheme of brick building construction that would be more economical, and yet more earthquake resistant than the usual constructions, has been developed, analysed and fullsize specimens tested on shake table to prove the scheme. It consists of half-brick thick load bearing walls (11.4 cm thick) with reinforced concrete vertical elements (11.4 cm × 11.4 cm with one bar 12 mm) built with the walls at spacings of not more than 1.5 m. Horizontal reinforcing elements are located at door and window lintel level. The scheme is suitable up to two storeyed buildings, the earthquake resistance being such that such buildings could be used in the severest seismic zones in India, such as the north-eastern region. The saving in cost of civil construction could be as much as 30% as compared with the usual load bearing wall construction.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Tarapada Banerjee

Banerjee obtained his MSc degree in chemistry from Dacca University in 1930 and DSc from the same university in 1936. He was Professor of Material Resources Development at Xavier Institute, Jamshedpur during 1932-35. Thereafter, he worked as a lecturer at the Dacca University (1937-48). He joined the National Metallurgical Laboratory, Jamshedpur in 1948 and retired from the post of Director of this Laboratory in 1966. He continued there as Emeritus Scientist up to 1970.

The fields of specialization of Banerjee have been photochemistry, electrometallurgy, extractive metallurgy and corrosion. His significant research achievements have been: (i) Production, for the first time, of induced optical anisotropy in inorganic colloids; (ii) Electrodeposition of alloys of constant composition; (iii) Propounding of a mechanism for phase transformations in electrolytic alloys (internationally recognized as Banerjee's mechanism); and (iv) Development of processes for the production of electrolytic manganese and manganese dioxide; these processes have been exploited commercially both in India and abroad. Banerjee has to his credit outstanding work on coinage alloys.

In recognition of his contributions to electro-metallurgy, Banerjee has won a number of awards, including the Cooper Memorial Medal (1953) of the Indian Institute of Metals; Dr K G Naik Gold Medal (1958) of the M S University, Baroda; Mint Foundation Medal (1962); Certificate of Merit, Board of Dictionary of International Biography, London (1972); and Diploma of Distinguished Achievements, Cambridge (1973).

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A B Bhattacharyya

Bhattacharyya has been one of the pioneers of research effort in India in the area of microelectronics. The range of problems addressed by him truly reflects the complexity and dynamic evolution of contemporary microelectronics technology. Starting his research work on the physics and modelling of solid state devices, he envisaged the importance of technology and design. The integration of physics, technology and design makes his research effort comprehensive in character. Further, the work also reflects the perception that ultimately the utility of the work lies in system application. While digital system had been the early beneficiary of micro-electronics technology, the real world information is always available only in analogue form. For the useful range of time bandwidth product, there is no unique technological option in signal processing. Bhattacharyya has pioneered research in all the three key options of analogue signal processing—surface acoustic wave device, charge coupled device, and semi-custom analogue gate array.

Charge coupled device has been one of the areas where basic contributions have been made. A new type of area variable MOS capacitor has been invented in which for the first time an electronically programmable solid state capacitor has been implemented[1]. The effective area can be changed by varying the voltage on the gate of a capacitor. The underlying principle involves the concept that in an inhomogeneously doped semiconductor, the inversion layer area of an MOS capacitor can be changed by varying the voltage. The device has been used for capacitive weighting of an electronically tunable transversal filter for signal processing. It has also been demonstrated that the bandwidth of a charge coupled device can be extended by 100% by suitably modifying the clock voltage, where a small barrier may be introduced to arrest the back flow in a CCD at higher frequency, thereby increasing the bandwidth[2].

The quality of thermally grown gate oxide is one of the most critical issues in CCD technology. In order to improve the lifetime of minority carriers and to passivate the mobile sodium, it is the usual practice to grow chlorinated thermal oxide. It was established for the first time that chlorine oxide introduces shallow traps. These traps have been identified and established by a technique of C-V measurements with thermal detrapping[3,4]. Also, the nature of hole traps has been investigated in chlorinated oxide[5].

Depletion mode MOS transistors fabricated using non-implantation techniques have a wide range of applications in LSI/VLSI structures. A technique has been developed by which

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the measurement of a single parameter—the output conductance—at suitable operating points could extract the relevant parameters of depletion MOST. The measurement not only gave the best accuracy in predicting implant depth and average doping but also had high sensitivity to error in measurement[6]. In the depletion MOST family, a new mode of high speed MOS operation—punch-through accumulation mode—was predicted with fundamental experimental evidence that in a punch-through situation the work function between the gate and the substrate is not that between the gate and the channel[7].

In the field of surface acoustic wave technology, a new concept of track changing of surface wave in a piezoelectric solid was introduced by partial illumination of interdigital transducers. The advantage of such an approach lies in the fact that it enables track changing in weak piezoelectric materials with fewer finger pairs[8]. Although SAW devices are usually fabricated on bulk piezoelectric material, a new dimension can be added if the device could be realized on a silicon substrate. ZnO/Si has been the potential multilayer structure. Unfortunately, the common technique of RF magnetron sputtering of ZnO causes significant radiation damage, introducing instability. A new structure, metal-zinc oxide nitride-silicon dioxide silicon (MZNOS) has been realized, where the nitride layer acts as a barrier to radiation damage. The technology is a significant step towards realization of stable monolithic SAW structure[9]. The physical modelling of SAW configuration in a multilayered medium is quite complex. A novel approach of transmission line analogy brings about orders of simplicity to solve the otherwise complex problem[10]. The approach is also extendable to capacitance extraction of VLSI structures from layout[11].

The passivation of GaAs for MOS field effect application has been one of the important technological challenges in the development of GaAs-based devices. Unlike Si-SiO_2 structures, MIS structure in GaAs lives with the problem of large surface state density. The work on GaN insulator film on GaAs has shown that with proper thermal treatment, the above structure would show largely reduced interface state density[12]. The well established Zerbst plot for the determination of lifetime has been extended to make it suitable for characterizing MIS structures on III-V compound where the passivating insulator is leaky[13].

Bhattacharyya has carried out research on a number of solid state devices—bipolar transistors[14], varactors, punch-through diodes, tunnel diodes and dynamic RAM[15,16]

Microelectronics being exorbitantly expensive, research proposition is a dilemma for any developing country. While there is no escape from involvement in microelectronics for developing countries, there are judicious options to be embarked upon. Bhattacharyya's present involvement in research on analogue gate array for telecommunication circuit[17] is an experiment towards establishment of the thesis that semicustom approach is the most relevant one in modern high-tech dilemma of developing countries[18].

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R B Chakravarty

Chakravarti was engaged throughout his career on planning, design and construction of river valley works, some of which required special studies. Some of these studies and researches had to be undertaken in cases where major difference of opinions existed. A few of these are discussed here in brief.

(1) Farakka Barrage Project

On joining the project (on deputation for a limited period for planning and giving a start to the constructions) Chakravarty had first to take a decision about the design of coffer dams to be constructed in the deep part of the river Ganga, on which depended the success of the barrage itself. The comprehensive paper of Karl Tarzaghi on cellular coffer dams indicated that this is the usual procedure adopted in such constructions. Without mentioning any reason, he had, however, admitted that there had been some failures. Since such a failure in the case of Farakka barrage (to be constructed right in the river) would be disastrous, Chakravarty studied the possible causes of failures in the past. His studies indicated that in the Ganga at Farakka this would not be feasible because of the deep scour depths (below the dry weather bed) during the flood season. This would require driving the cellular piles more than 50 ft. His studies also indicated that driving of cells in a circular form would tend to increase in diameter at the bottom (as in a bell-mouth), which would increase the hoop-tension in the pile lines. The pile lines would not be able to take the strain below a certain depth of drive. (Then there would be the likelihood of vortex-flow adjoining.) Subsequent studies made by Chakravarty on model piles (cellular design) confirmed the expanding diameter of the cells.

Chakravarty next studied the question of seasonal coffer dams, using single pile line backed by earth embankment. To overcome the difficulty of facing the sharp local scour pockets at the forward end of the pile lines being driven, he devised suitable sand dredgers, which would constantly pour in dredged sand in the pocket. He had the dredgers made for the purpose.

After he came back to his parent department under West Bengal Government, the project authorities engaged a team of foreign experts and on their advice decided to go ahead with the cellular coffer dams in the deep part of the river. In 1966, Chakravarty was taken in the Technical Advisory Committee and he raised the question before this committee. The foreign experts could not answer the point raised on the expanding nature of circular cells at the lower ends, nor on the question of effect of vortex flow during the

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flood season, which in any case was to be faced in the case of each of the cellular coffer dams. The foreign experts expressed the opinion that they would prove their contention on the river itself. This was agreed to by the authorities and a number of cells were set up (just outside the barrage area) during 1967. Also, a single cell was driven near the river bank (drive about 35 ft). The cells in the river bed could not withstand even the first flood. The extracted piles of the single cell indicated that the joints had opened up at about 30 ft depth. After this, the coffer dams were made according to the seasonal design (not to face the flood seasons) and the work was completed in three seasons.

(2) Navigation Canal Entry

The Design Organization (under the Ministry of Irrigation and Power), in consultation with their navigation expert, laid down that the entry into the canal from the barrage pool should point upstream of the river. Studies made by Chakravarty indicated that under such an arrangement, river vessels would not be able to enter the canal from the river during the flood season. His suggestion for having the canal entry pointing downstream in the river was not readily acceptable to the authorities concerned, but they agreed to have the idea of Chakravarty and their idea tested on models. This was done with three alternatives for the entry pointing upstream in the river; all of them proved unsuccessful. The idea of Chakravarty (based upon his academic studies) proved a success. The latter proposal was then adopted.

(3) Closure of River Piali

In the Sundarbans Delta Project, the proposal is to close all the tidal rivers in the Sundarbans, which have virtually not much of catchment area on the country side. Piali is a small tidal stream falling into the Matla river (another tidal river). Despite best efforts, the channel could not be closed. Then the help of Chakravarty (who had retired quite about 10 years earlier) was sought. He took one year in studying the problem which proved to be difficult and tricky. For an extensive depth the bed material consisted of organic substances from the esturine water with some (very fine) silt. This had practically not much bearing resistance. The use of timber piles was ruled out. Even steel or concrete piles were not considered feasible for the depth to be encountered. The caisson method was considered risky because of the likelihood of tilting. Chakravarty studied the reasons of failure in the earlier attempts which mainly depended upon the structural strength of the closure work and not on the foundations. His studies indicated that it would be feasible to take advantage of the slippery nature of the bed material, in sliding down of two parts of the first cross-dam (to stop the flow of tides), from the two banks of the river. These were to be built with sand bags crated in nylon netting and laid in bonds like brick masonry. (Any gap left in the centre was to be filled up with dumping similar crates.) This would also push out the upper part of the soft bed. The first cross-dam would deteriorate in saline water in a few months and was, therefore, to be supplemented by proper earth dam on the downstream of the sand bag cross-dam. To prevent local subsidence (which would cause failure of the construction), the daily filling was to be kept uniform and extremely small, so that additional load added each day may be taken up by the increased bearing resistance gained due to the gradual squeezing out of the water from the waterlogged bed material. Care was also to be taken to prevent vortex flow and deep scour pockets (one of the reasons for earlier failure) being formed. The whole structure was expected to sink slowly along with the construction until requisite bearing resistance was achieved. In actual construction, the sinking was as anticipated from the studies and continued not only during the six months of the filling up work but also for another four months, after which there was an abrupt stoppage of sinking, indicating that full bearing power was achieved. Future observations did not show any further sinkage in the foundations. Thus, a non-conventional procedure developed from his studies proved a success in the form of a simple and cheap method for tackling the problem.

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D Chakravorty

Oxide glasses have conventionally been used as insulators. During the last decade, glasses with semiconducting characteristics have been developed which owe their properties to the presence of some transition metal ions in them. Chakravorty has shown that electronic conduction in bulk oxide glasses (as distinct from thin films of cermet glasses) can be induced by precipitating metal grains in a controlled manner within the matrix. The metal dispersoids have dimensions of the order of a few hundred angstroms. The electrical conductivity arises due to electron tunnelling between the metallic islands. These materials also exhibit optical absorption characteristic of inhomogeneous media, which can be predicted on the basis of available theoretical models. The required microstructures are currently achieved either by an ion-exchange technique followed by a reduction treatment or by suitably choosing the starting glass composition. The kinetics of the metal phase precipitation has been shown to be markedly dependent on the heterophase structure of the ion-exchanged glass. In fact, it has been found that a glass-crystal interface improves the efficiency of metal phase nucleation in the matrix.

Memory switching behaviour has been observed in certain glasses having dispersed metal particulates of bismuth. A theoretical model has been developed to explain this effect on the basis of particle-stretching consequent to the application of an electric field. It has also been found that by changing the microstructure as well as the thickness of such glass-metal systems, both threshold and memory switching can be induced in the same composition.

Chakravorty has shown that semiconducting behaviour in oxide glasses can also arise due to the presence of antimony and arsenic, which have variable valence states like Sb^{5+}/Sb^{3+} and As^{5+}/As^{3+} respectively. The resistivity behaviour of these materials tends to follow a bipolaronic conduction model.

A glass fibre drawing process has been developed by Chakravorty and his coworkers in which the conventional bushings made of platinum-rhodium alloy have been replaced by cheaper ceramic bushings made of either pure alumina or stabilized zirconia. A slip-cast technique has been used; the maximum size of these bushings has a total of 80 nozzles.

Glass fibres having a microstructure consisting of metallic granules of submicron dimensions dispersed within the matrix have been developed. These fibres have been found to be electrically conducting.

By subjecting some alkali-containing glass fibres to an ion-exchange reaction

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Advanced Centre for Materials Science, Indian Institute of Technology, Kanpur 208016 involving silver, it has been possible to induce a high level of ionic conductivity in these materials. The possibility of using them as fast ion conductors is presently being explored.

A new method has been developed to make glass-metal microcomposites using the sol-gel route. It is expected that a wide variety of such composites can be prepared by this technique. Novel electrical, magnetic and mechanical properties are expected in some of these materials. Work in this direction is now in progress.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B N Das

The research activities of Das started with investigations on the optimization of directivity of antenna arrays, individual elements of which are not isotropic. The array elements which are mutually coupled are transformed into an equivalent array, the pattern functions for which satisfy orthogonality condition, and are hence not mutually coupled. The transformation is carried out using the eigenvectors of the impedance matrix. For radiators possessing symmetry, the eigenvectors can be determined from the corresponding geometrical matrix. The derivation of expression for the directivity gets simplified considerably[1]. The corresponding excitation coefficients were evaluated, and sensitivity of the array to statistical fluctuation in amplitude and phase or excitation assessed.

Das carried out extensive investigations on slot radiators in the wall of rectangular waveguide[2] as well as in the ground plane of strip and microstrip line[3]. He found analytical expressions for self and mutual impedance between slot radiators using Dyadic Green's function formulation. Later, similar expressions were derived using angular spectrum of plane waves. The effect of decay of amplitude of excitation resulting from radiation from individual slots was evaluated. The method of hardware design of a slot array for a desired radiation was also worked out.

In the case of strip and microstrip line fed slots, analytical expressions for the impedance of slot were evaluated from complex power radiated and discontinuity in the modal voltage. A method for deriving the expression for modal vector function required for evaluation of discontinuity in modal voltage was developed[3]. This approach to the problem was attempted for the first time.

Extensive theoretical and experimental investigations were carried out on the design of phased array and its feed. The dependence of the number of elements of a phased array on grid configurations was evaluated. Analytical expressions for the dimensions of isosceles triangular grid were derived as a function of coverage sector of a phased array. It was established that for a particular coverage sector, maximum saving in the number of elements is achieved not only for equilateral triangular grid configuration but also for isosceles triangular grid configuration for a base angle of 30°. The suitability of using different radiating elements to different grid configurations was established. Das solved the problem of phase-only control for beam shaping. This makes a phased array more versatile. This work was done for the first time[4,5]

During the progress of work in phased array, it was felt that one of the important

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components to be used in the constrained feed of phased array using waveguide radiator is the end launcher type of coaxial to waveguide transition. Since no information was available in the literature on this vital component, investigations were carried out to solve the problem of hardware design of this component[6,7]

Solution for the problem of electromagnetic coupling between waveguides coupled through long aperture was obtained for the first time. The analysis is based on equivalent circuit approach. Analytical expressions were derived for long aperture coupling between waveguides with their axes parallel and perpendicular to each other using slots in the broad as well as the narrow wall of the waveguide. An expression for equivalent network parameter as well as coupling has been derived[8-10].

It is convenient to use strip and microstrip lines for design of constrained feed of phased array. While designing the different building blocks of phased array feed using these lines, it was noted that many important aspects of these lines had not been explored and investigations on these problems were necessary.

The same generalized conformal transformation which can be used for the analysis of asymmetric and symmetric strip line as well as microstrip line was found for the first time[11]. Conformal transformation was then used for the evaluation of field intensity in these lines. This generalized formulation was used for analysing homogeneous as well as inhomogeneously filled strip and microstrip lines.

The conformal transformation technique and Green's function formulation were used for the analysis of nonplanar strip lines. Characteristic impedance and field distribution were evaluated for the particular cases of circular and elliptic cylindrical strip lines[12].

Conformal transformation was also determined for the general case of oval shaped conducting strips between grounded conducting planes. From this generalized formulation, formulae were derived for conductor with elliptic boundary having major axes parallel and perpendicular to the ground planes and arbitrarily located between ground planes. The cases of circular, horizontal and vertical strips have been analysed using the formulation[13]. Analysis has also been carried out for an inhomogeneously filled line.

Das has made valuable contribution to the problem of aperture coupling between dissimilar lines. The formulation has been applied to the case of aperture coupling between waveguide and strip as well as microstrip lines, with their axes parallel and also when they form a T-junction[14].

The formulation of coupling between parallel non-coplanar arbitrarily located planar strips between ground planes and above-grounded conductor has been made in terms of mutual inductance and capacitance[15].

Useful investigations were done in the fields of microstrip antennas and TEM cell which is used for tackling EMI/EMC problems. Excellent laboratory facilities have been created for advanced research in microwave networks, strip and microstrip lines, phased arrays and other types of antennas.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

J Das

The major interest of Das in communication systems and theory originated from his thesis work on 'Studies on pulse slope modulation—A new TDM system and some topics in telecommunication'[1;2]. His research in signal approximations and digital communication led to the development of a highly efficient digital communication system, viz., adaptive delta modulation. Over the years, he has built up a school of study and research in digital communication systems and bandwidth compression techniques at the Indian Institute of Technology, Kharagpur. He has also guided research on active filters and data communication. He has contributed more than 50 scientific papers, some of them jointly with his students, and guided PhD work in the areas of network approximation and synthesis, bandwidth compression, asynchronous pulse modulation systems, PCM and ADM, incoherent-carrier communication systems, coherent and wideband communication systems, and random access communication systems.

As a result of the studies on the various aspects of digital communication noted above, the following digital subsystems/ systems were developed over the years:

(a) PCM codecs[3–5],

(b) ADM codecs[6–9]: (i) binary (ii) ternary, and (iii) 6/12/24 channel MUX system,

(c) Low-bit-rate codecs[10,11], and

(d) Modems[12].

The ADM MUX system suitable for VHF/UHF communication links is being now manufactured by a public sector unit for mobile and area-grid communication. The work of the group was recognized through the NRDC Invention Promotion Award in 1976 and also by the VASVIK Award in 1977. Das also received the Silver Jubilee Award of IETE in 1978.

Along with the above work on synchronous digital systems, investigation on asychronous digital systems led to the development of rectangular wave modulation[13] and pulse interval modulation[14]. These were intended for simple communication systems and were later incorporated in random access systems for mobile communciation[15]. The problem of incoherency of carriers using solid-state lasers was solved by developing optimum modulation techniques and this resulted in a novel method of eliminating fading effects in scatter communication[16].

Das was associated with defence R and D for a number of years. He and his group were responsible for carrying out a number of projects on digital communication and allied topics, sponsored by DRDO and also by ISRO.

The current interests of Das are in

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random access communication systems and spread spectrum techniques.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B L Deekshatulu

Deekshatulu conducted research during 1960-70 in many aspects of control systems in India when this discipline was in infancy elsewhere in the world. He introduced new courses at postgraduate level and taught all subjects (aspects) of control systems, besides guiding postgraduate and doctoral programmes. He has about 60 publications in this area.

In 1972, he initiated and developed complete digital image processing and remote sensing facilities for research, teaching and operational applications and is continuing his activities of research, development and guidance in this area. He developed many interpretation/analysis instruments like drum scanner, additive colour viewer, image analyser, optical reflecting projector, densitometer, microfiche camera, etc. He provided guidance towards the development of many software packages for correction of remote sensing data and application to survey and inventory of natural resources. He has about 30 publications in these areas.

Remote sensing is primarily a tool, albeit, a complex one. There are many deficiencies in this tool which limit its applications in different branches of science. Two important problem areas in remote sensing are: (i) effect of the earth's atmosphere in obscuring and distorting the objects and their spectral reflectances, and (ii) geometric and radiometric errors which corrupt the remotely sensed data. Deekshatulu's main current and future interests include correction of all geometric errors, with special reference to satellite derived multispectral data and development of atmospheric models which can correct for atmospheric distortions. He also plans to carry out resources discipline oriented research using current and future remote sensing satellite data for more effective utilization of this new tool.

Remote Sensing

Deekshatulu was a member of the faculty (in various capacities as lecturer to professor) of the Department of Electrical Engineering and School of Automation, Indian Institute of Science, Bangalore, during 1960-1976. He initiated and developed the digital image processing and remote sensing facilities for teaching and research. He constructed a grey scale and colour drum scanner. He conducted research in image processing and its applications. He demonstrated picture enhancement applications in X-ray studies, finger print identification, forensic studies, etc. He was a visiting scientist at IBM Watson Research Centre, and Willow Run Laboratory, USA for 15 and 2 months respectively and worked on digital image

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processing and data compression techniques during 1971-72.

At the National Remote Sensing Agency (NRSA), as Head of Technical Division (1976-1981), he planned and developed remote sensing data analysis, ground truth, photoprocessing and R&D facilities. He guided and developed several image classification techniques and optoelectronics equipment like drum scanner, densitometer, multispectral additive colour viewer, optical reflecting projector, microfiche cameras, light table with coordinate measuring system, analog image analyser, etc. Know-hows on these equipment were transferred to industry and most of them are available today commercially.

As Director of NRSA (since January 1982), he is guiding and directing important programmes of the organization like aerial and satellite data acquisition, processing, dissemination and training. His current responsibilities include setting up of a complete ground segment for reception, processing and dissemination of data from Indian Remote Sensing Satellite (IRS) proposed to be launched in mid 1986, preparing the users for use of IRS data and setting up a Regional Remote Sensing Service Centre at Dehradun.

Control Systems

At the Indian Institute of Science (IISc), Bangalore, he introduced and taught control systems discipline to several courses at graduate and postgraduate level. His teaching and research work covered the areas of adaptive control, optimization, optimal control, biocontrol, etc. He organized the post-graduate course in control systems and assisted in the setting up of School of Automation at IISc.

Deekshatulu is associated with several national and international professional institutions/associations at various levels in the areas of remote sensing, electronics, computer, control systems, etc.

Future Plans

The following are some of the areas which need further studies in remote sensing: Sources of geometric errors in satellite multi-spectral data and methods to correct them; atmospheric models to correct atmospheric distortions; discipline oriented research for effective use of the new technology and also data available from future satellites.

(i) *Geometric correction of satellite data* : The data received from a remote sensing satellite are geometrically inaccurate because of errors in the scanner (line length correction and mirror scan nonlinearity), platform ephemeris and attitude (roll, pitch and yaw) of the satellite in addition to errors due to earth's rotation, curvature and atmospheric refraction. While it is tempting to model all these errors and (along with accurate calibration measurements) correct for all of them, such an approach is infeasible, mainly because of the difficulty of accurately measuring some of these errors like attitude errors. An alternative approach is to register these data with a corrected image using ground control points. Such an approach is feasible but costly because of the large number of ground control points (GCPs) which would be required. Automatic identification of GCPs and correction still remains a formidable task. A judicious combination of the above two approaches seems the best solution. After correcting the data using models for the different sources of errors, further refinement can be carried out using GCPs.

Errors due to misregistration, noise, spatial transient response, field size, etc., cause classification faults. For example, if the pixel size is not small enough, a single pixel may contain more than one object and will either be misclassified or may fall outside the classification limit. These need further study.

Since remote sensing satellites are sun synchronous, data are always collected at approximately the same local solar time. Because of this, the effects of different local solar times on class separability need attention.

(ii) *Effect of the atmospheric and other scientific applications problems* : The atmosphere attenuates and distorts the signal coming from the earth's surface to the remote sensing sensor. The gases and aerosols present in the atmosphere scatter, absorb and emit radiant energy. The atmosphere is transparent in certain narrow regions of the visible, infrared and microwave regions.

The atmosphere scatters, absorbs or emits radiant energy. Rayleigh or molecular scattering is dominant in the visible and near-ultraviolet regions and increases with the inverse fourth power of the wavelength. It is necessary to overview the existing atmospheric models and develop new ones for correction of atmospheric distortions, study effect of the atmosphere on classification, etc.

It is necessary to develop models which will correct the anisotropic reflectances in remotely sensed images from mountainous regions covered with vegetation. The anisotropic reflectances are further complicated by variable surface orientations. Earlier studies on the anisotropic reflectance problem assumed that orientation does not affect the reflectance. Recent studies have shown that the approach is feasible only for non-vegetated surfaces. It is necessary to refine the model.

The following are some of the application specific problems which need further study: (1) Detecting forest disturbances by incorporating DTM information; (2) Fuzzy lineament extraction algorithms for enhancement of lineaments in geology; (3) Structural analysis of geological phenomena using simulated illumination conditions of satellite data; (4) Study of problems in oil and gas exploration; (5) Gaseous pollution monitoring; (6) Estimating green biomass; (7) Estimation of vegetation index; (8) Changes in reflectance for changes in solar zenith angle; (9) Development of quantitative relationships among soil properties and reflectances—fundamental studies; (10) Correlation of chemical properties of different targets and their corresponding spectral reflectances; (11) Knowledge-based and intelligent classification algorithms; and (12) Special image processing techniques.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Dinesh Mohan

My active research career began in January 1948 when I joined the Central Building Research Institute (CBRI), Roorkee as a Senior Scientific Officer. Soon after I was designated as its Planning Officer and took over as Director in October 1962. I held this post for two decades till my retirement in July 1982.

Apart from planning the CBRI in all aspects, including buildings, staffing and equipment in its formative stage, I held charge of the Geotechnical Engineering Division for 10 years (1950-60). During this period, I organized and conducted research on a number of important projects in Geotechnical Engineering. My major achievements are discussed below in brief.

Black Cotton Soils

Almost 20% of the total land area in India consists of black cotton soils, concentrated mostly in Central India (Madhya Pradesh). These are heavy clays with montmorillonite as the predominant clay mineral due to which the soils have high shrinkage and swelling property. This property makes them problem soils for the Foundation Engineer. Prior to 1950, cracking of buildings founded on black soils was taken as an 'act of God'. I carried out some basic studies on the properties of these black soils, which finally led to the design and development of bored underreamed pile foundations. Apart from testing the physico-chemical properties and correlating them with engineering properties, such as compressibility, shear strength, bearing capacity, etc., a two-year field study was carried out on ground movements at various depths starting from the surface down to 4 m. The study revealed that movements were negligible at a depth of about 3 m; this gave a clue to the depth at which the foundations could be anchored safely. The tip of the pile was enlarged in the form of a bulb, to 2.5 times the diameter of the stem, to act as an anchor and also to provide a greater bearing area. A simple and manually operated underreaming tool was developed for this purpose. Full size piles were load tested and their bearing capacities determined in loading and pull out. These were correlated with the engineering properties of the soil and a rational design was thus formulated. Further improvement of the technique led to the development of multi-underreamed piles which had more than one bulb on the lower portion of the pile. Each extra bulb could carry 50% greater load. These piles could thus carry heavier loads and they proved economical as compared to large and uniform diameter bored piles being used so far.

A further improvement was made in the form of Bored Compaction Piles. These

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were either uniform diameter or single underreamed piles in which concrete, still in the green stage, was compacted by ramming a close ended steel tube through it. It ensured better compaction of the concrete as also strengthening of the ground adjacent to the piles. These piles have 50-100% greater load carrying capacity compared to the normal bored piles, and are specially suited for soft to medium dense soils ($N < 15$). An Indian Standard Code of Practice has been brought out to help the design and construction engineer. These foundations need simple and light equipment and are 25-50% cheaper than the traditional strip or pile foundations. A large number of buildings of all types—towers, hydraulic structures, etc.—have been constructed on these foundations and from all quarters satisfactory reports regarding their subsequent behaviour and substantial economy achieved have been obtained.

Pile Foundations

Pile foundations are generally required for heavy structures founded on poor soils like those existing in Bombay and Calcutta. These are required even for normal soils carrying tall structures and high rise buildings. Prior to 1950, pile foundations were being designed and executed by a few foreign owned piling firms. The design was mostly empirical and was based on experience. Most of the pile foundations were therefore, overdesigned and the clients accepted them, since no simple guidelines were available to them to check designs.

I carried out detailed investigations on all aspects of pile foundations. These studies led to the formulation of a number of Indian Standards and Codes of Practice on different types of pile foundations. My studies and those carried out elsewhere were incorporated in my third annual IGS lecture entitled “A close look at the problems of research and application to pile foundations”[1].

Site Investigation and Subsoil Explorations

Site investigations are a very important part of any major foundation project. Faulty or casual site investigation and soil testing has led to many foundation failures necessitating costly remedial measures.

A careful study was made of the existing techniques of site investigations, and new and simple techniques were developed. One example is the dynamic cone penetration test which can replace the internationally accepted standard penetration test. The latter is laborious and time-consuming. Another example is the one-point method of liquid limit test which simplifies and speeds up the most common soil test to determine the consistency of a soil.

Primary School Buildings for Rural Areas

There is great shortage of primary schools in the country and the shortage has been further aggravated by the national objective of providing free and compulsory primary education to all children. The conventional designs and methods of construction of primary schools are costly and time-consuming.

The Central Building Research Institute, under my direction, carried out a scientific study of the use efficiency of spaces in the conventional type primary schools of Uttar Pradesh. It led to an improved design giving considerable saving in space and cost of construction. Further economy and speed in construction were achieved by the use of prefabricated roofing components and local materials and labour. A very large demonstration project covering 2500 primary schools in rural areas of Uttar Pradesh was carried out by CBRI during 1977-79. In the first stage, each school had two classrooms and a small store; it could be later expanded into five classrooms and a headmaster's room. The design led to a saving of about 20% in cost and 50% in time of construction over the traditional types. It also provided employment opportunities for about 2.3 million man-days, of which about 0.67 million man-days were for skilled workers and about 1.6 million man-days for unskilled village labour. The prefabricated roofing units and other components were developed as a consequence of the research carried out at the CBRI.

Health Care Buildings in Rural Areas

With the stress on better health care for the rural areas, the World Bank financed a major project for the construction of primary health centres, subcentres, family planning centres and allied buildings in rural areas of Uttar Pradesh. CBRI was called upon to act as the Chief Consulting Architect for the design of these buildings.

Under my direction, CBRI had carried out extensive studies in the functional design of health care buildings in rural areas. These studies came in very handy for the design of the World Bank project. Considerable economy in space was achieved through judicious planning. Prefabricated roofing components were used to further economize in cost and time of construction.

In recognition of my work, CBRI brought out in March 1985, a publication entitled "Three decades of building research in India" and named it as "Dinesh Mohan Volume".

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

D K Dutta Majumder

Dutta Majumder did his MSc (Tech) in Radio Physics and Electronics in 1955 and PhD in Digital Computer Memory Technology in 1963 from the University of Calcutta. In late 1955, Prof. Prasanta Chandra Mahalanobis, the then Director of the Indian Statistical Institute (ISI), recruited him to work in the newly started Electronic Computer Division of ISI. While working on the installation, maintenance and servicing of the first two electronic computers in India for a period of about two years, he got interested in research and development activities in cybernetics, computer science and related information technology and designed and fabricated several experimental systems, such as electronic random number generator, a track switching system using saturable core magnetic reactor, electronic correlation computer using Hall-effect multipliers, several new drum memory systems, an automatic memory core and plane testing equipment, etc. In 1962, he was appointed Senior Research Engineer of the Division. After he got his PhD in 1963, he was awarded a United Nations fellowship as a visiting scientist to work in different leading computer research and development centres in USA, particularly at the University of Michigan, Ann-Arbor.

On his return, he started a small research group and carried out extensive and intensive research work in the field of memory technology—core memory, magnetic bubble memory, associative and distributive type of memory, solid state memory, holographic memory, etc. and published about 30 research papers in this field.

The book *Digital Computers Memory Technology* (Wiley Eastern Ltd) based largely on the work of Dutta Majumder and his students is recognized as the only book in the international market, which covers the entire memory technology under one cover. In 1969, Dutta Majumder and his colleagues were awarded Sir J C Bose Memorial Award of IETE for their original contributions in memory core and plane testing equipment.

While working in memory technology, his interest shifted towards the field of pattern and speech recognition by human-beings and by learning machines which is, in a sense, a functional aspect of the memory systems.

In late 1960s, his group developed a statistical model for computer recognition of human speech pattern and other patterns along with its hardware implementation; research in the diverse areas of signal processing, pattern recognition, learning machines, image analysis and man-machine communication systems began in full swing at the ISI. Since early 1960, Dutta Majumder has

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been engaged in teaching and training research workers, practising engineers and commercial people in computer science and technology and todate ISI has trained a large number of computer scientists.

Dutta Majumder was appointed Professor and Head of Electronics and Communication Sciences Unit of ISI in 1972. In early 1970, he got interested in a new mathematical tool known as fuzzy set theory and its application in pattern recognition and image processing and developed several methodologies and computer algorithms using fuzzy set theory for solving problems in diverse aspects of pattern recognition and image processing, particularly in the field of speech recognition and speaker identification. He and his students have published over 60 research papers on speech processing, spoken word recognition and speaker identification problems.

During the late fifties and early sixties, Dutta Majumder developed basic interest in the field of cybernetics and systems theory and since then he has been adopting in his research work a unified approach involving control theory, communication science and computer science. In early 1970, he also started working in the field of computer communication and conducted some important studies on infrastructural requirements for computer communication network and distributed databases in developing countries like India. He and his students have published over 20 papers on computer communication. He also wrote some papers on the unified aspects of theory of cybernetics and general systems theory as a result of which he became in 1977 the first recipient of the Norbert Wiener Award given jointly by the World Organisation of Cybernetics and General Systems and the journal *Kybernetes*. By mid-1970, his group became one of the internationally recognized research groups in the fields of statistical syntactic and fuzzy set theoretic approaches in pattern recognition, image analysis, artificial intelligence, shape analysis and computer vision problems.

As an off-shoot of pattern recognition research, he also started working in biomedical signal processing and associated areas and developed a non-fading patient monitoring system for ECG and EEG to be used in the intensive care units of hospitals as a project from the Department of Electronics, Government of India. More than 10 papers have been published by the Biomedical Group of ECSU in ISI under his guidance.

In 1982, he was awarded R L Wadhwa Gold Medal of IETE for his 10 years' contribution in the field of electronics.

For the last 10 years of so Dutta Majumder's group has been actively engaged in developing different methods, tools and techniques in the above-mentioned fields for applications in natural resources studies, biomedical analysis and diagnostic, military applications, man-machine communication, computer graphics, artificial intelligence, computer vision systems, technical aids for handicapped, etc.

As an extension of their research in speech processing, Dutta Majumder and his colleagues got interested in conducting scientific study of Indian classical music in collaboration with Sangeet Research Academy of Calcutta and several papers have been published so far as a result of this work. One of the papers by Dutta

Majumder and his colleagues on musical acoustics of Hindustani raga sangeet was awarded Sir C V Raman Award by the Acoustical Society of India in 1985.

Under his guidance, the computer communication research group is currently engaged in conducting statistical studies on the tropospheric region in eastern India with Accustic Radar Systems to study its efficacy in establishing microwave and other links. The work is being carried out in collaboration with National Physical Laboratory and Calcutta University as a project under the Department of Science and Technology, Government of India, under the guidance of Dutta Majumder. He has recently extended this work to study the pollution pattern over Calcutta, a work of great practical importance.

Since mid-1970, Dutta Majumder and his students have made significant internationally recognized contributions in the field of image processing and shape analysis for applications in artificial intelligence and computer vision. He has published more than 50 research papers in this field. The book "*Fuzzy mathematical approach to pattern recognition*" (Wiley Eastern Ltd) based on the contributions of Dutta Majumder and his colleagues has become an important reference source in the field and has been selected for the best production award in the 1986 World Book Fair.

Dutta Majumder and one of his colleagues have been working on the application of fuzzy set theory in control of different power systems which is an altogether new approach and have published about 10 research papers on fuzzy logic controller of non-linear multivariable generating systems. He has recently published some papers on the application of fuzzy mathematical approach to national planning problems.

Dutta Majumder is currently the Principal Investigator for several research projects under Ministry of Defence, Department of Science and Technology, and Department of Electronics of the Government of India. He is coordinating the Fifth Generation Computer System Research sponsored by the Department of Electronics, Government of India in the fields of artificial intelligence, computer vision, pattern recognition, image analysis and intelligent interface systems. The number of his research publications exceeds 225. He has edited three books and has coauthored three books. He received Computer Society of India, Calcutta Chapter award in 1983, Michael Madhusudhan Award in 1984 and an award from Bangiya Pandit Sabha in 1983.

Dutta Majumder is a Fellow of IETE (India), ex-Chairman, Computer Society of India, Calcutta Chapter, Fellow, Indian National Science Academy, Indian Physical Society, Indian Cryogenics Council, and Chairman, IETE, Calcutta Centre. He represented India in IFIP(TC-10) for two years, and is a member of the Governing Council of the International Association of Pattern Recognition (IAPR) and Chairman, Indian Unit of Pattern Recognition and Artificial Intelligence (IUPRAI). He is also President, Indian Society of Fuzzy Mathematics and Information Processing (ISFUMIP) and is Liaison Officer in Asia of the World Organization of General Systems and Cybernetics.

Dutta Majumder is associated in different capacities with several universities, scientific agencies and academies in the country. He has been participating in and contributing on invitation to the deliberations of the major national and international conferences in his fields of interest.

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S C Dutta Roy

Over the past 25 years, we have been involved in some exciting research problems on circuits, filters and signal processors using various kinds of devices, viz. lumped and distributed, passive and active, and analog and digital. The main goal of our efforts has been to make them efficient, reliable, economic and compatible with the demands of fast changing technology. The present account highlights the results which we consider as important advances.

(1) Lumped Networks

We investigated various kinds of frequency selective RC networks, viz., the Wien, parallel-T, bridged-T, bridged ladder and shunted ladder[1], and evolved new design and tuning procedures. We obtained concise mathematical formulae for a general ladder network and applied them to the design of RC phase shift oscillators, and to the problem of potential distribution across a string of insulators, as encountered in power distribution. For RC ladders, we derived closed form expressions for the delay and rise times. We found general solutions for the insertion network required to maintain constant voltage or current in a varying load.

(2) Passive Network Synthesis and Filter Design

Minimal realization of nonminimum phase biquadratic RC transfer functions; equal valued, common terminal capacitor synthesis of RC one-ports; and synthesis of optimal passive integrators are some of our interesting contributions to passive network synthesis.

We showed that practical dissipative reactors can be used in constant resistance filters. We investigated, in detail, sharp cut-off filters[2] obtained by introducing transmission zeros in the stopband, and gave simplified design procedures for them. A new family of transitional Butterworth-Chebyshev filters; a simple method for obtaining arithmetic symmetry in bandpass filters (BPF's); and a minimum phase low pass filter (LPF) with flat delay and equi-ripple magnitude, are some of our other contributions to filter design.

We worked out a method for reducing overshoot and ringing in the step response of conventional filters, and provided a definite answer to the outstanding question concerning optimum pole locations of filters for pulse applications[3].

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(3) Distributed Networks

The distributed RC network (DRCN) is an important byproduct of IC technology; we worked on the theory of uniform (U) as well as nonuniform (NU) DRCN's, and their applications in phase shift oscillators[4], notch filters[1] and wideband delay lines.

The NU transmission line (NUTL), of which the NUDRCN is an example, is governed by a differential equation, which is not, in general, exactly solvable. We developed systematic procedures for finding solvable NUTL's and a simple method for finding their two-port parameters[5]. Even for a solvable NUTL, analysis and synthesis problems are quite involved because of the transcendental nature of the network functions; we developed simplified rational models for obviating this difficulty.

We carried out extensive investigations on an impedance matching network using lossless TL's originally suggested by Ruthroff. We found that using a NUTL, one can increase the matching bandwidth drastically, and that the Ruthroff connection applied to a cascade of two appropriate UTL's leads to frequency independent or allpass matching[6]. Our other contributions in lossless TL's include a general result on coupled NUTL directional couplers; a new NUTL for voltage pulse compression; and general formulae for cascaded commensurate UTL networks.

We found a useful application of the DRCN concept in modelling solid state devices. For example, we showed that the transistor alpha could be exactly represented by a capacitor terminated exponential NUDRCN. Another application of the DRCN which we pursued[7] to great depths is in network approximations of the irrational function s^λ, $0 < \lambda < 1$. Recently, we have worked out excellent lumped approximations of $s^{1/2}$, $(s+1)^{1/2}$ and $(s^2+1)^{1/2}$, by using a flexible continued fraction expansion technique.

(4) Inductance (L) Simulation, Active RC Synthesis and Filter Design

At low frequencies and in IC's, inductors have to be avoided, or simulated. Our early work on L-simulation was based on properties of semiconductor devices, but their excessive temperature sensitivity made us look for alternative philosophies. The high quality integrated operational amplifiers (OA's) provided the answer and we succeeded in simulating temperature and OA parameter insensitive grounded as well as floating L's. Various circuits were proposed by us, including one for ideal L, and critically studied[8]. In the case of floating L's, our solutions are economic and avoid the critical adjustment problem usual with other known circuits. We applied the simulated L's to the direct as well as cascade form active filter design and derived a number of new, versatile, economic and low sensitivity second order blocks.

Our other contributions to active RC synthesis and filter design include single OA all-pass circuits; active RC synthesis of driving point functions; a single OA multifunction second order structure; equal, grounded C realization of all-pole transfer functions; and a novel technique for calculating the sensitivity of third and higher order filters[9].

(5) Digital Signal Processing and Filtering

Most of our recent research has been concentrated in this very dynamic and active field, and our early efforts were concerned with digital filter design starting from known analog filters. Later, we developed a computationally efficient matrix formulation of the discrete Hilbert transform, and applied it successfully to the design of a digital LPF.

Finite word length effects, resulting in coefficient quantization and multiplication roundoff errors, were extensively studied by us. Our contributions include relation of architecture to quantization errors in second order digital notch filters; new, efficient methods for evaluating multiplication roundoff errors; application of pseudo-Boolean technique to FIR[10] and IIR designs for minimization of coefficient quantization errors; a new "nested" structure for FIR filters, which achieves, with fixed point implementation, the same accuracy as that of floating point[11]; and new low sensitivity recursive structures.

Single parameter controlled variable digital filters, as required in speech processing and spectrum analysis, using a first order (1°) all-pass transformation on an IIR prototype gives rise to delay free loops; we devised a simple computational trick to avoid this problem. For an FIR prototype, we evolved an efficient 2° cosine transformation which obviates the limitations of the usual 1° case. We also derived efficient methods for designing BPF's with fixed centre frequency and variable bandwidth or vice versa.

We evolved a new and general method for frequency domain interpolation[12], in which the order of computation is retained at the FFT levels, and gave an efficient solution to the problem of time domain interpolation by using low order differentiators[13]. An exclusive time domain solution has been proposed by us for estimating the frequency of a single sinusoid embedded in broadband noise, using iterated autocorrelation technique.

We worked extensively on digital filtering using identical blocks, initially concerned with sharpening the response, and later extended to frequency transformation and variable filtering. Also, the design of maximally flat nonrecursive filters has been reduced to a completely analytic procedure due to our efforts.

(6) Charge Transfer Device and Its Applications to Signal Processing

The charge transfer device (CTD) is uniquely suitable for many signal processing situations but its applications have so far been limited due to its charge transfer inefficiency (CTI). We investigated a number of techniques for CTI compensation, and developed a new one, based on feedback[14], which could give exact compensation of an N-stage CTD with N feedbacks. We also showed that only two feedbacks are adequate for practical purposes, and using this concept, we evolved a simple and accurate method for measuring the CTI.

We showed that the coefficient sensitivity in a CTD transversal filter could be drastically reduced by implementing it with difference coefficients, and evolved a new concept for economic implementation of the prime transform algorithm in a CTD transversal filter.

(7) Work in Other Fields

Besides the fields elaborated so far, we have worked on a few interesting problems in measurements and instrumentation, electronic circuits and antenna arrays. Of these, shunt fault diagnosis in a resistive ladder, single resistance controlled RC oscillators[15], and design of four element nonuniformly spaced antenna array, deserve special mention.

(8) Future Directions

One future research will mostly be concentrated in the field of digital signal processing and filtering, with a view to developing direct and analytic design procedures, which are not extensions of their analog counterparts, and which minimize dependence on computer optimization. What we have achieved so far is only partial success; much more needs to be done to establish this field on the same firm and analytic grounds as analog signal processing and filtering.

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R J Garde

The problems related to streams flowing through alluvial strata, commonly known as alluvial streams, are most complex and are of great relevance to India. Garde has been involved in finding generalized solutions to the various problems using laboratory data collected under controlled conditions, field data and analytical/numerical techniques.

Lowering of a stream bed around bridge piers has been studied in the laboratory to assess the quantitative effect of pier shape and dimensions, sediment characteristics and flow characteristics on the maximum scour depth. The available field data collected in India have also been utilized to obtain relationships[1-3]. This information is useful in determining the depth to which the foundations of bridge piers should be taken. Presently, the transient scour around bridge piers during the flood is being studied using laboratory data and numerical modelling.

In dealing with flow in alluvial streams, one is confronted with the problem of changing bed and water surface forms with change in flow conditions. These changing regimes affect the resistance to flow and sediment transport rates. Garde has arrived at the criteria for predicting regimes at flow for given flow characteristics. Two criteria evolved use $\tau_0/\Delta\gamma_s d$ and Froude number, and R/d and $S/\Delta\gamma_s/\gamma_f$ as the two sets of parameters. The latter criterion is more suitable for predicting resistance, since it does not involve the dependent variable U, the average velocity of flow[4]. The prediction of average velocity in a stream is required for estimating the discharge; this prediction is complicated by the fact that resistance to flow is dependent on flow conditions. On the basis of analysis of data from laboratory flumes and natural streams covering a wide range, Garde obtained a unique relationship for velocity[5], namely,

$$U \Big/ \sqrt{\frac{\Delta\gamma_s}{\rho_f} R} = F\left((R/d)^{1/3}\,(S/\Delta\gamma_s/\gamma_f)\right).$$

All alluvial streams carry sediment and knowledge about the rate of sediment transport for given flow conditions is essential in problems concerning stability of streams, their improvement, aggradation and degradation, and reservoir sedimentation. The bed load, suspended load and total load data from natural streams together with data collected in laboratory flumes have been analysed to obtain equations for transport rates. Bed load transport of uniform sediment is given by[6]:

$$\phi_B = 4.6 \times 10^7 \tau_*'^{8} \text{ for } \tau_*' \leqslant 0.065$$

$$\text{and } \phi_B = \frac{8.5\tau_*'^{1.8}}{\left(1 + \dfrac{5.95 \times 10^{-6}}{\tau_*'^{4.7}}\right)1.43}$$

$$\text{for } \tau_*' > 0.065$$

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where ϕ_B is the bed load transport rate (dimensionless); and τ'_*, the grain shear (dimensionless). When the material is nonuniform, one gets what is known as partial transport at low shear. In such cases, the transport rate of a given size d_i can be obtained by correcting the dimensionless shear as $\xi_e \tau'_0 / \Delta\gamma_s d_i$ for a given size d_i in the mixture. ξ is found[7] to be a function of τ'_0/τ_{oc}, $\tau'_0/\Delta\gamma_s d_i$ and Kramer's uniformity coefficient, M. Similar analysis has been carried out to study the distribution of suspended load, total suspended load and total load carried by streams[8,9].

The majority of irrigation channels in the Indo-Gangetic plain are unlined and flow through alluvial material. Several attempts have been made in the past to obtain governing relationships for the channel geometry for given flow conditions. This problem has been analysed using stable channel data from India, Pakistan, USA and Egypt. It has been shown that the area (A), depth (D) and perimeter (P) are given by the functional relationship[10].

$$\frac{A}{d^2}, \frac{P}{d} \text{ or } \frac{D}{d} = f\left(Q/d^2 \sqrt{\frac{\Delta\gamma_s d}{\rho_f}}, \quad g^{1/2} d^{3/2}/2 \right).$$

The functional relationship for each dependent ratio has been obtained. Relationships for slope and sediment transport were also established. It was shown[11] that the shape of stable channels can be described by Fourier sine series and the Fourier coefficients are functions of Q.

In the case of natural alluvial streams, the longitudinal slope is affected by change in discharge and sediment load, and reduction in the size of the bed material due to hydraulic sorting and abrasion. Depending on the relative importance of each of these, the slope can decrease, increase or remain constant along the length. An expression has been derived for such a change in slope as a function of x. It has been shown that

$$\frac{S}{S_0} = \exp\{(0.178\alpha_3 - 0.426\alpha_2 - 0.747\alpha_1)x\}$$

where α_1, α_2 and α_3 describe[12] how sediment size, mean annual discharge and catchment area change with x. Some basic work on the possible explanation for meander formation has been done recently[13].

In recent years, considerable interest has been evinced in transient flows in alluvial streams. These transients are caused by man-made interferences in the regime of the river, such as construction of dams and embankments, addition or removal of sediment, addition or withdrawal of discharge and changes in stream slope. A systematic study has been undertaken to physically observe the phenomena[14-16] and to analyse the problem analytically/numerically. In the simplest form, the process can be described by a diffusion equation or a wave equation. Comparisons have been made between observed and computed bed problems for transient caused by overloading of stream[14,16] Experimental work is also in progress about progressive coarsening of the bed material in a degrading channel[17] and a numerical scheme is being formulated for computation of degradation. Sedimentation data from eight Indian reservoirs have been analysed to develop a method for predicting progressive silting of reservoirs[18,19]

Future Plans

As regards the analysis of transient flows, at present it is assumed that the stream remains unchanged in its plan form. However, large changes in discharge, sediment or slope can modify the plan form and this needs to be included in the mathematical analysis. Further, taking into account the precipitation, vegetation, drainage density and lithology, it is proposed to make detailed calculations regarding sediment yield from various catchments in the country to assess the rates of erosion. The existing mathematical models will be applied to the problem rivers like the Kosi and the Brahmaputra to predict their behaviour and make comparisons with the actual data.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

V M Ghatge

Ghatge got his DPhil from the University of Gottingen, Germany in 1936. Thereafter, he has been Professor, Aeronautical Engineering, Indian Institute of Science, Bangalore; Managing Director, Products Designers Pvt Ltd; and General Manager, Hindustran Aeronautics Ltd, Bangalore. His post-university career has been confined mainly to design and development work on aircraft and certain accessories.

Notable among Ghatge's contributions are: (1) Designing and development of a troop-carrying glider; (2) designing, development and productionizing of (a) HT-2, a trainer aircraft for *ab initio* training of pilots (being used for training purposes by IAF and civilian flying clubs); (b) the two-seater ultra-light aircraft 'Pushpak' for use in training pilots in flying clubs; and (c) an aircraft for AOP duties and agricultural purposes; (3) designing and building up of an aircraft for logistic air support purposes; (4) designing and development of the jet trainer aircraft 'KIRAN' for the Indian Air Force; and (5) designing of a jet engine (2500 lb thrust), whose prototype is under fabrication as a suitable power plant for 'KIRAN'.

Among the awards won by Ghatge are Padma Shri (1965), Sir Walter Pucky Indian Prize for Production Engineering (1969), and the National Design Award.

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N S Govinda Rao

Govinda Rao and the late V Ganesh Iyer started the Hydraulic Research Station at Krishnarajasagar (Mysore State).. In collaboration with him, he designed the world's biggest siphons each with a discharging capacity greater than that of the river Thames in London. He has written a memoir on the design of siphons. V Ganesh Iyer was awarded a gold medal for his invention of a new type of siphon and Govinda Rao was awarded a certificate of merit for designing the siphon and writing out a memoir on the same subject.

After he became Professor of Civil and Hydraulic Engineering in the Indian Institute of Science, Govinda Rao started a school of research on cavitation. He propounded a new theory on cavitation damage along with one of his students, A Tiruvengadam. He established a criterion for accurate determination of inception of cavitation along with another student, Sehgal. The effect of cavitation on pre-rotation in centrifugal pumps was the subject of another article with Ramaprasad. Another article with M V Rama Murthy dealt with the effect of cavitation on the performance of quadrant edge orifice. Govinda Rao designed a new type of cavitation tunnel in collaboration with H K Nanjundaswami. The 6 in tunnel cost one fourth of a similar type of design made by a foreign firm and was supplied to one of the research stations in India. Govinda Rao contributed numerous articles on the subject of cavitation. He was awarded the President's Gold Medal for his work on this subject, being the fourth recipient of this medal in 30 years, since its inception by the Central Board of Irrigation and Power.

His contributions in the field of open channel flow hydraulics include the design of a new type of current meter for the measurement of discharges in rivers for which he has taken a patent. His main contribution is in the field of characteristics of high velocity flow. He organized a school of research in this field along with his students. He has made significant contributions in the following areas: (1) Submerged hydraulic pump; (2) Diffusion of high velocity flows; (3) Dissipation of energy of high velocity flow through friction block and other types; (4) Branch channel flow; (5) Scour due to high velocity flow; (6) Turbulence in open channel flows; (7) Inception of air entrainment in high velocity flow; and (8) Measurement of flow.

His work on measurement of flow with D Muralidhar received international recognition by being adopted for laying down international standards for the measurement of flow over broad crested weirs. His work with Keshavamurthy on

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high precision measurement of flows by evolving new types of weirs has been widely recognized. His works with N Rajaratthnam on submerged hydraulic pump and on friction in rotating discs with Srinivasa have received wide publicity.

In the field of hydraulic machines, Govinda Rao has taken patents for evolving a low delivery head high discharge centrifugal pump; a new type of domestic water supply meter; a sprayer; a laboratory pore pressure measuring device; and a prestressing device.

He has published nine books on various topics and lectured in Australia, India, Thailand, Germany and UK.

He was one of the pioneers in research in soil mechanics and foundation engineering, which is a new branch of civil engineering started by Terzaghi in 1926. He published a number of papers in this subject, specially on the subject of soil dynamics. He was elected President of the Indian National Society of Soil Mechanics and Foundation Engineering (now called the Indian Geotechnical Society) (1966 and 1967) and was also invited to participate in the South East Asian Conference on Soil Mechanics in Bangkok in 1967.

Among the honours and awards conferred on Govinda Rao are Hon Fellowship of Institution of Civil Engineers (India) (1972); Fellowship of the Indian Standards Institution (1973); K F Antia Prize (1973); Jawaharlal Gold Medal of the Institution of Engineers (India) (1970), and President's Gold Medal of the Central Board of Irrigation and Power, Alumni Award for Distinguished Scientists of the Indian Institute of Science (1985), and Silver Plaque from the Institution of Engineers (India), Karnataka Centre (1985). In 1966, he delivered the Nidubhushan lecture of the Institution of Engineers (India).

He is a member of the International Association for Hydraulic Research, Delft, Holland; Fellow, American Society of Civil Engineers; Fellow, Indian National Science Academy (formerly National Institute of Sciences of India), and the Indian Academy of Sciences.

Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Jai Krishna

Jai Krishna has been a pioneer in the development of research and training in earthquake engineering in India. Under his leadership, the subject has developed at a very rapid rate and has led to the creation of facilities for undertaking work on earthquake resistant design of structures of all types.

Jai Krishna has the unique distinction of introducing into the engineering syllabi, the first course in soil mechanics in 1948 and structural dynamics in 1958 and initiating research in earthquake engineering in India in 1960[1]. Design work and research on civil engineering structures have been his major concerns. His work has brought in new ideas in the design of earthquake resistant structures leading to economical design and construction practices. Some of his noteworthy contributions include: (a) evolution of simple methods of strengthening brick buildings to resist earthquake forces[2-4], (b) design, fabrication and installation of strong motion instruments in India to collect seismic data for structural design[5,6], (c) earthquake resistant design methods for dams[7,8], bridges[9], water towers[10] and other major structures[11,12], and (d) introduction of the concept of iso-acceleration lines indicative of earthquake forces in epicentral tracts for study of distribution and attenuation of energy[13-15]. Since the common man's dwellings made of brick or stone have been largely responsible for most casualties due to earthquakes, his methods have been adopted on a large scale in the seismic areas of India and abroad.

Another area which attracted his attention was the lack of seismic data for design of structures in the seismic zones in India. This is a field in which still considerable ignorance prevails, since the forces coming on structures during an earthquake are a function of the amount of energy released, the depth of focus, the energy absorbing capacity of the intervening media and the distance from the source of energy. To collect this information, India had to stand on its own feet and instal strong motion instruments in the main seismic zones of the country. Under his guidance, a large number of structural response recorder stations have been established in India and sophisticated strong motion accelerographs have been developed; a number of them have already been installed in various river valley projects and other places.

Jai Krishna has carried out special field investigations for 1963 Skopje and 1966 Debar earthquakes in Yugoslavia, 1967 Koyna and 1970 Broach earthquakes in India; iso-acceleration maps were prepared from the study of damage and non-damage of structures, and sliding and over-turning of objects. These studies have helped in establishing a correlation of

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structural damage with ground acceleration and study of attenuation of ground acceleration away from the epicentre under the influence of local soil conditions. Such studies, supplemented with strong motion instrumental records, help in making precise estimation of ground motion at project sites at various distances from the seismo-tectonic lineaments along which major earthquakes may occur in future.

Jai Krishna has taken a leading part in the field of standardization. The codes of practice for design and construction of earthquake engineering structures developed by the Indian Standards Institution under his chairmanship have helped the country in providing adequate safeguards against earthquake forces. These codes are being constantly reviewed and updated in the light of knowledge and data which become available from time to time under his guidance.

Jai Krishna has given guidance and direction to the international community engaged in earthquake resistant analysis and design, emphasizing each time the need for collection of data and making realistic assessment of properties of materials of construction so as to predict the dynamic response of structural systems more reliably. The results obtained by many analysts are based on idealized conditions and simplified assumptions. The exact nature of damping and dynamic behaviour of various types of structures and construction materials, ground-structure interaction and ground motion characteristics in different geological terrains are not fully understood and still await solution for evolving better and economic design and construction practices. What is required is intensification of research activity in these spheres and to have adequate data about ground motion by having a close network of strong motion instrumentation. He has actively pursued these ideas and, as a result, two strong motion instrumentation arrays are now being installed, one in Kangra and the other in Shillong region, which are the two major and potential regions of seismic activity in India. Extensive instrumentation in the entire Himalayan belt is also envisaged. Results of these studies are likely to generate useful seismic data for design in future.

Jai Krishna has suggested that the work carried out so far on brick buildings should be taken up more extensively and model testing of large size models be done on controlled vibration tables for investigating the actual behaviour of such structures during realistic ground motions. These studies would go a long way in improving the design of such buildings, since the gap between real behaviour and the estimated analytical behaviour is very large in this case. According to him, the direction to be taken by earthquake engineering research should be towards experimentation and scientific modelling of various physical problems to verify the results of sophisticated analytical procedures which have developed over the past few years with the advent of high speed digital computers.

Some of the major gaps in the knowledge on science and technology of earthquake engineering are: (i) Relationship between occurrence of micro-tremors and major earthquakes, (ii) Relationship between the energy released by an earthquake at the source and the energy reaching the ground, and (iii) the energy absorption pattern of structures standing on ground in various forms. Intensive research projects to fill these gaps need to be taken up.

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R Krishnan

Phase transformations and structure-property correlations in metals and alloys have been the main field of interest of Krishnan. The investigations have been carried out using optical, X-ray and electron metallographic techniques.

X-ray line profile analysis for the determination of the structure of cold worked metals and alloys, with special emphasis on stacking fault probability investigations, had been the interest of Krishnan in the early days. His paper incorporating the results on cold worked uranium[1], published in *Acta Metallurgica*, was the first paper to appear in this journal from India. That stacking faults could occur in other non-close-packed systems which exhibit a layer structure has been an important contribution and the first observation of stacking faults in uranium[2]; it has been often quoted in literature.

Stacking fault energy is a parameter of importance in understanding the behaviour of metals and alloys. Alloying additions play a significant role in altering the stacking fault energy. The decrease in stacking fault energy on alloying is essentially dependent on the occurrence of suitable phases adjacent to one another in the equilibrium diagram of the system. The above conclusions have been reported in literature[3,4].

Phase transformations and structure-property correlations have been the major interest of Krishnan in recent years. Martensitic transformation in zirconium and titanium based systems has been studied extensively. That two different morphologies with distinct fine structure are associated with each morphology has been clearly brought out in several publications[5–10]. The effect of fine structure in imparting increased strength has also been studied[11].

Decomposition of eutectoid alloys is of interest again from both basic and applied angles. A wide variety of Zr-base alloys have been studied and the fine structure arising out of such eutectoid transformations and the relationships between such structures and mechanical properties have been reported[12].

Precipitation reactions in the solid state are an equally important class of transformation and these have been studied in the case of Ta-C, Zr-Nb and Zr-Ta alloys. Interesting morphologies have been reported[13–15].

The effect of pressure on phase transformations in NiS, CrS, UO_2 and UP has been another aspect studied and a number of papers have been published. That the alpha to omega transformation under pressure in zirconium occurs via the

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beta-phase has been proved conclusively on the basis of electron microscopic observations.

Radiation damage and superconducting materials have been other areas in which Krishnan has been active.

Since joining the Naval Chemical and Metallurgical Laboratory, his research interests have got diverted to the study of titanium and its alloys as condenser tube materials, use of high molybdenum stainless steels and their corrosion behaviour in sea water, and development and production of transducer materials. Development of suitable easily weldable steels for submarine applications is another important area of work.

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R A Mashelkar

Mashelkar's contributions are primarily in the areas of polymer reaction engineering, transport phenomena in polymeric systems and engineering analysis of non-Newtonian fluids. Some of the key features of this work are indicated below.

(1) Unified Free Volume Framework for Polymeric Systems

Realizing the importance of the role of free volume in controlling the transport phenomena in polymeric systems, a model based on the concept of altered free volume state (AFVS) was developed. One of the merits of AFVS model is its simplicity and its ability to correlate transport phenomena in diverse polymeric systems in a common framework. The model has been used for analysing and correlating molecular diffusion in polymeric solutions, gels, melts and solid polymers which could be semi-crystalline, crosslinked or filled. The model parameters can be meaningfully correlated with the structure of penetrants, which validates the physical significance ascribed to them. Within a single framework of AFVS model, it has also been possible to analyse the sedimentation behaviour of polymer solutions and the viscosity behaviour of protein solutions and polymer blends. Particularly notable success has been achieved in the correlation of viscosity of polymer solutions and latex viscosity.

While using the model for the analysis of polymer solution viscosity, it has been shown that the model parameters could be used as tools to identify transition from one region to another. Additionally, a novel scaling parameter ϕ was defined, which could take into account the effect of polymer concentration as well as molecular weight on the solution viscosity, obviating the need for empirical shift factors used for the past few decades to bring about the superposition.

In addition to elucidating the effect of various parameters, such as concentration, particle size, shear rate and electrolyte concentration on latex viscosity, development of the AFVS model makes it possible to isolate the geometric and electrostatic contributions to latex viscosity. A unique superposition has been shown to result for the effect of shear rate on the immobilization parameter for various electrolyte concentrations.

(2) Transport Phenomena in Polymeric Systems

Stress-induced macromolecular migration : It has been realized only recently that in non-homogeneous deformation fields, structured liquids (such as macromolecular solutions) do not behave as homogeneous liquids do. Instead, there exists a non-uniform distribution of macromolecules within the

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flow domain and this occurs due to the phenomenon of stress-induced migration. Such effects pervade diverse transport phenomena involving macromolecular solutions.

Mashelkar's efforts were focussed primarily on two distinct areas—the mechanism of stress induced migration and its consequences in pragmatically important areas. The analysis of the phenomenon for dilute solutions led to the discovery of the FDCF asymptote (the upper bound on the migration effect) in the process, raising some fundamental questions regarding the flow lengths necessary for full development. A heuristic analysis, which exploits the stress-induced migration phenomenon, was developed to provide a rational interpretation of anomalous behaviour in areas as diverse and as important as secondary oil recovery, free coating, laminar drag reduction, heat and mass transfer involving viscometric and non-viscometric flows and longitudinal dispersion. Likely pitfalls in several experimental techniques were elucidated and new strategies were proposed for attacking transport problems involving macromolecular solutions.

Anomalous transport processes in polymeric media : Carefully designed experiments on gas absorption in rapidly stretched films of polymeric solutions showed some hitherto unreported and dramatic differences. The absorption rates were reduced when films were generated under rapid stretch conditions over axisymmetric bodies of revolution. whereas they were enhanced when films were generated without stretching. This observation threw fresh light on the behaviour of viscoelastic liquids in extensional flows. Contrary to the popular notion that drag reduction phenomenon is associated with a reduction in heat/mass transfer processes, it was shown that absorption rates could be enhanced on polymer addition in freely falling turbulent films. The unique observation of anomalous absorption rates in mixed surfactant-polymer systems has many potential applications.

The phenomenon of velocity independent transport phenomena in rapid external flows of viscoelastic fluids has been truly perplexing. The conventional approach of a boundary layer type analysis was seriously questioned for such flows and a new concept of elastic boundary layer was proposed to explain this phenomenon.

(3) Polymer Reaction Engineering

Polycondensation reactor simulation : Polyethylene terephthalate (PET) is a major polymer with applications in both fibre and engineering plastics industry. The production of PET involves esterification or transesterification stages leading to bis-hydroxyethyl terephthalate and its subsequent polycondensation.

Many complexities arise while trying to mathematically simulate this process. The process of direct esterification (or transesterification) as well as polycondensation is accompanied by the formation of a number of side products, which critically control the tensile strength, stability and dyeability of the fibre. For a rational analysis, consideration of the entire kinetic network thus becomes essential, but it poses formidable problems too. In the finishing stages of polycondensation, diffusional factors play an important role. The problem is essentially that of desorption of a number of volatile side products accompanied by a series of reversible reactions. This poses conceptual as well as numerical difficulties in modelling.

Comprehensive modelling effort was undertaken and used successfully for simulating industrial reactors. This effort has led to significant productivity and product quality improvements, while at the same time resolving a number of anomalies. For instance, an apparently anomalous observation of the enhancement of polycondensation rate with the formation of side products due to the enhancement of driving force for the desorption of the key volatile product (ethylene glycol) explains some of the curious observations with industrial reactors.

Analysis of copolymerization reactors : This work was undertaken with the specific objective of providing a comprehensive methodology for the analysis of copolymerization reactors operating at higher levels of conversion, an area of considerable industrial importance, which was hitherto unexplored.

A new approach via deterministic and stochastic analysis to resolve the existing conflicts in the estimation of reactivity ratios emerged from this work. An experimental investigation of the gel effect in copolymerization showed clearly its influence on cumulative composition distribution (CCD), sequence length distribution (SLD) and molecular weight distribution (MWD), which control the polymer properties. Also, the types of multiplicity and stability behaviour expected in the continuous isothermal and non-isothermal copolymerization reactors were examined for the first time.

(4) Directions of Future Research

The phenomenon of stress-induced macromolecular migration has opened up new areas of investigation. The potential of stress-induced macromolecular fractionation, examination of the possibility of stress dependent activity coefficient in polymerization systems, and the development of a free volume based approach for predicting thermodynamic equilibria in stressed polymer solutions are some of the areas which need urgent investigation. In polymer reaction engineering, a number of challenges remain. These include modelling of solid state polycondensation systems, modelling of precipitation polymerization with the special aim of examining the industrially important problems of cyclic behaviour, modelling of modern gas phase polymerization systems, etc. The discovery of polymers with exceedingly high capacities for water absorption (up to 1000 g/g of polymer) in this laboratory has opened up new vistas related to the study of thermodynamics of swelling polymers, studies of structure of water in swollen polymers, theoretical and experimental investigation of critical phenomena occurring during gel collapse and also the development of novel separation techniques for recovery of biological molecules from dilute aqueous solutions.

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S R Mehra

Some methods of processing local soils and low grade aggregates to make them acceptable for use as durable materials in civil engineering projects were evolved by Mehra.

(1) Mehra's Method

For cheap all-weather roads in rural areas, having low traffic and medium rainfall in the vast alluvial plains, the locally available soils are first 'blended' together to form a reasonably well graded and stable mixture, and are then mixed with about 40% of local low grade aggregates (0.75 inch downwards); the whole mixture is compacted at "optimum moisture" to produce a hard road crust capable of withstanding the prevailing traffic under different local weather conditions.

The road crust thus formed is at least as durable as the traditional water bound stone macadam, but costs, on the average, less than 50%, the cost of maintenance being the same. More than 600 km of such roads have been constructed over the years and are doing well.

This method has the following additional advantages:

(i) Unlike water bound macadam, no progressive rutting takes place; whatever slight tracking due to wear occurs during the dry weather is "ironed" out by traffic during wet weather, because of the elasto-plastic property of the soil mortar surrounding each aggregate particle. Consequently, the surface wears evenly over the years.

(ii) Water bound macadam draws its internal structural strength from the tight interlock between adjoining pieces of stone aggregate created by virtue of heavy rolling with copious quantities of water. In course of time, the interlocking sharp edges of the stone aggregate get rounded off progressively, resulting in loosening of the interlock, consequential unravelling of the stone and failure of the road crust.

In Mehra's method, however, the proportion between the aggregate and the soil is so adjusted that the pieces of aggregate are individually surrounded by a thin layer of "stable" soil, which, by virtue of its cohesive and elasto-plastic properties, acts not only as a binder to hold the aggregate together, but also protects the soft aggregate from damage under the vibratory load of traffic.

(iii) In addition to being much cheaper, the method relieves to a large extent the strain on the national transport system by drastically cutting down on import of stone from long distances.

(iv) The method is labour intensive, and lends itself to gradual mechanization in due course.

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(v) The method is applicable to a large percentage of roads in rural areas.

(vi) Such roads lend themselves ideally to "stage construction".

(vii) Such roads can be easily given a bituminous surfacing, where necessary.

(2) Low Cost Permanent Housing

A method for processing local soil economically in the alluvial plains to make it fit for use in place of burnt bricks in permanent housing in sub-urban and rural areas was developed by Mehra in the late forties. Against a cement requirement of 10-12% recommended internationally, which is uneconomical for a country like India, the new method involves the use of a very small quantity of cement. This reduction in cement requirement was achieved through the following expedient actions:

(i) Locally available soils were first blended together to produce a well graded mix, to reduce the quantity of expensive stabilizer needed to make the various soil mixes, when compacted at their predetermined "optimum" moistures, proof against damage by weather action.

(ii) The standard "wetting and drying and freezing and thawing" test was modified for use in tropical and subtropical regions (where frost is either non-existent or nominal), by cutting out the "freezing and thawing" portion of the standard test.

Actions (i) and (ii) together had the amazing effect of drastically reducing to a mere 2.5% the quantity of cement required to give both strength and weather resistance to the compacted local soils comparable with those of burnt brick masonry, at less than half the cost. About 4000 residences in 12 different localities were constructed over 36 years ago and are giving good service. This was by far the largest cement-soil housing project in the world.

(3) Water-proof Mud Plaster

Most of the houses in the Indian villages are constructed using sun-dried bricks, and are given protection with mud plaster. As neither of the two are resistant to water action, a lot of houses are destroyed during the rains. Even the replacement of mud plaster with cement or lime plaster is ineffective, as moisture penetrates through and causes failure.

An attempt was, therefore, made to water-proof the mud plaster itself. The addition of a specially prepared slow-breaking bituminous emulsion to the extent of only 5% to the traditional mud plaster mix was found to render it virtually water-proof in the sense that it has withstood the following rigid test most successfully: A spray of water, under a head of 12 ft, was played on a plastered outside wall for six days and nights continuously; subsequently the wall was subjected to alternate wetting and drying cycles (wetting with the same spray for 12 hours at night and sun drying during the day) for 50 days. No moisture penetrated through the half inch plaster layer and the joint between the mud plaster and the "kacha" brick face remained intact.

As a convenient substitute for the special emulsion, a bituminous cut-back gave comparable results. The plaster is useful not only for mud walls and roofs, but also for the lining of irrigation water courses to cut out seepage losses.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

H K Mitra

Mitra has made notable contributions in the field of refractories, with particular reference to the requirements of the iron and steel industry.

In the 1920's, frequent failure of iron-making blast furnace lined with firebrick was traced to the reversible reaction $2\ CO \gtreqless CO_2 + C$. The forward reaction at 350°-500°C was hastened by the catalytic presence even of small percentages of iron oxides in firebrick during its manufacture. The carbon monoxide present inside the blast furnace penetrated through the pores of the firebrick and in the entire zone of the above temperature range from top to near bottom, away from the much hotter face lining, disintegration started. Copious deposition of carbon in the above zone was the cause. It was akin to stabbing in the back. The offending oxide was identified by Mitra and Silverman[1] and a method was developed to make it innocuous to CO attack during the manufacture of firebricks.

Evolution of comparatively simple and less time-consuming test methods is important, especially for a hetrogeneous material like firebrick. Cold crushing strengths of firebricks obtained by Mitra[2] furnished basic data for the current standard test for this property.

Premature failure of conventionally made firebricks used for lining ladles to transfer molten steel from the furnace to ingot moulds was a serious problem for the steel industry four decades ago. The concept of introducing 50-100% pre-calcined clay or 'grog' in the mix from which firebrick is made altered the picture. The life of such "high-grog" bricks was higher by about 70% compared to a normal firebrick. High 'grog' content prevented contraction of firebricks by heat from molten steel, and also the opening up of numerous joints between an individual brick, as is the case with the conventional brick. These opened up joints were the points of attack by molten metal and slag in the case of the latter. "Hi-grog" brick is now a standard material for other industrial applications in addition to its use for ladles[3].

Another novel development besides the above is making of firebrick from entirely non-plastic raw material[4]. Addition of a plastic clay is considered essential for normally made firebricks.

A process developed by Mitra[5] involves lining of acid-Bessemer converter with deliberately underfired silica brick with consequent true density of not less than 2.4. This improves lining life to about 2,000 blows compared to approximately 350 blows with the lining done earlier with a variety of natural sandstone.

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Austrian magnesite deposit with high impurities cosidered beneficial enabled that country to have monopoly of supply to the entire industrial world of magnesite refractories, an essential requirement for steel industry. Paradoxically, pure variety of Indian magnesite deposit was considered unsuitable for the purpose. This untenable situation was altered by commerical manufacture and use by Mitra[6] of magnesite refractories from Indian raw magnesite.

The use of non-refractory raw materials, i.e., those with melting point below 1500°C, as the starting input for the manufacture of refractory products, had hitherto been inconceivable. By the application of phase rule, two such nonrefractory raw materials, one a chrome ore and the other a magnesium silicate rock, were converted to super-grade refractories[7,8]

The logic of the above three research efforts demanded design, erection and commissioning of a commercial manufacturing facility. This resulted in the super-basic refractories plant[9] now in operation at one of the Indian steel plants.

Energy crisis shifted the direction of research everywhere in the industrialized countries. The hub of all research, not excluding ours, was aimed at softening the blow of the crisis. Insulation firebricks capable of withstanding direct exposure to 1500°C and above were commercially available for the first time in the country. This, in turn, made possible the installation of our pioneer all-insulation furnaces to effect substantial fuel economy, reducing fuel consumption by as much as 40%. Different aspects of this work were reported in two papers[10,11]

Early in the forties, the Indian Ceramic Society appointed a special committee under the Chairmanship of Mitra to formulate a scheme for a Central Ceramic Research Station. The committee's report, or rather a detailed blueprint, was submitted in less than a year. What is now the Central Glass and Ceramic Research Institute, Calcutta, is a direct result of this report[12,13].

Another special publication of Mitra is the Satya Sunder Deb Centenary Memorial Lecture[14]. It gives a critical review of the Indian industrial scene, with a plea for breaking shackles of status-quoism by adopting an innovative approach.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

S N Mitra

While working in Cavendish Laboratory, Cambridge, in 1947, I developed a radio method for measuring horizontal drift in the ionosphere. The method has been named after me and has been used extensively throughout the world; it has been incorporated in standard textbooks and is the only standard method available today for measuring horizontal drift in the ionosphere. It formed a part of the programme of International Geophysical Year, International Geophysical Cooperation and International Quiet Sun Year.

I developed, for the first time, a statistical method for investigating random motion of ionospheric irregularities.

In 1954, I initiated a series of investigations on the ionospheric cross-modulation. While working in this field, I discovered the phenomenon of "self-gyrointeraction", under which a modulated CW transmission working at or near the gyrofrequency of free electrons in the ionosphere suffers a significant loss of percentage modulation. This is particularly valuable for planning medium wave service away from gyrofrequency.

While in All India Radio in 1954, I developed an automatic ionospheric absorption recorder to measure ionospheric absorption on vertical incidence pulsed transmissions. This was the first equipment of its kind developed in the world to measure absorption without any ambiguity and personal error. Collection of data at Delhi for a complete solar cycle of 11 years has enabled the development of a new formula for calculating field strength on short wave transmissions in the tropical countries. It is known as AIR formula and has been accepted by CCIR and ITU.

In 1955, while working with the automatic ionospheric absorption recorder, I observed a rare phenomenon called 'triple magneto-ionic splitting'. This phenomenon had been observed earlier through manual experiments by G R Toshniwal in Allahabad in 1935, but his results were not accepted, as theoretically such a phenomenon could not be seen at the low latitudes of Allahabad or Delhi. A suitable explanation was given for these rare occurrences at low geomagnetic latitudes.

In 1958, I developed a completely automatic ionospheric recorder for measuring ionospheric heights and critical frequencies on vertical incidence pulsed transmissions. This was the first equipment of its kind to be developed in Asia and it was taken over for manufacture by a defence laboratory.

In 1958, I developed a radio method for detecting all types of flare occurring on the

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Sun. The results achieved so fai have proved beyond doubt that it is by far one of the best ground-based systems for detecting solar flares. This method is being used by other organizations in India and abroad. Late Sir Edward Appleton, Nobel Laureate, has called this method as a 'notable discovery'. I was elected a Fellow of the Indian National Science Academy (1961), Indian Academy of Forensic Sciences (1965), Royal Astronomical Society, London (1965), Indian Standards Institution (1981) and Institution of Telecommunication Engineers (India) (1972).

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Roddam Narasimha

My major scientific interest has been statistical fluid mechanics relevant to aerospace technology and atmospheric studies, and in particular the structure, dynamics and control of turbulent shear flows. The phenomenon of turbulence, which I have recently surveyed in detail[1], continues to be the major unsolved problem in fluid mechanics. In recent years, the realization has grown that turbulence and other chaotic phenomena present an extraordinary challenge as problems in physics and mathematics as well. "Weather" is also a form of turbulence of a particularly complex kind, as it manifests itself on a rotating sphere in a stratified two-phase medium (condensation of water vapour in the atmosphere can strongly affect the dynamics).

A brief account is given below of major lines of work in these and other areas that have been of personal interest to me.

(1) Structure of Turbulent Flows

Studies on the structure of a variety of turbulent flows have led to the formulation of five basic working rules[1]. Two of these studies are perhaps worth special emphasis.

Turbulent energy is generally produced in "bursts" whose dynamics are not yet well understood. An experimental study from our laboratory[2] suggested a surprising coupling mechanism that might lead to these bursts. This has been the subject of much debate in the literature, and our work in the atmosphere promises to shed more light on the phenomenon.

In another series of investigations we have examined what may be called the memory of turbulent shear flows. Here, a careful experiment was devised which unambiguously showed the presence of such memory; the effect was later incorporated into a simple mathematical model for turbulent shear flows.

(2) Relaminarization

Turbulence is generally thought of as the natural state of fluid flow, but under a variety of conditions reversion to the laminar state is possible—a discovery that at first caused much surprise, and is now beginning to find applications. Much experimental work has been done, particularly in my laboratory, aimed at elucidating the nature of this phenomenon, which incidentally occurs in rocket nozzles, wind tunnel contractions, curved pipes and a host of other situations. Extensive theoretical work has shown[4] that there are three classes of reversion. In the first, turbulence energy is dissipated through the action of a molecular transport property like viscosity or conductivity; in the second, turbulence energy is destroyed by work done against

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an external agency, like buoyancy forces or flow curvature. In both cases, experimental evidence indicates that the suppression of turbulence goes beyond the mere decay of energy to an actual decorrelation of the velocity components contributing to the crucial Reynolds shear stresses that govern the mean flow. The third class of reversion is by domination over slowly-responding Reynolds stresses, exemplified by a highly accelerated boundary layer. These and other forms of turbulence control are likely to become part of new technology in the coming decade[5].

(3) Transition

Transition from laminar to turbulent flow, a problem on which I started my scientific career[6,7], has again become of personal interest to me. The early work was undertaken at a time when a theory proposed by Emmons had made predictions which were not in quantitative agreement with observations from the National Bureau of Standards. I showed that the chief reason for this was a wrong assignment of *à priori* probabilities, and a new "hypothesis of concentrated breakdown" produced excellent agreement. This has since been used widely to provide transition models. In recent years, I have returned to the question, in part inspired by our work on relaminarization. We have recently studied the effect of pressure gradient at length and shown the presence of "sub-transitions" within the transition zone[8]. A comprehensive numerical model for describing the flow during the transition zone is now in an advanced stage of development.

(4) Atmospheric Studies

All of us live at the bottom of an atmospheric boundary layer normally about 1 km thick. Understanding this boundary layer is important for a variety of reasons, from the quality of the air we breathe to the dynamics of the monsoons. Further, it provides a 'laboratory' for studying turbulence at Reynolds numbers far beyond the reach of the biggest man-made facilities anywhere in the world.

In 1979, we set up a mast to make measurements at Balasore on the Orissa coast during the International Monsoon Experiment (MONEX). This provided the first measured values of surface fluxes in India. This was followed by an experiment during the total solar eclipse of 1980, when measurements were made at Raichur, using the eclipse as a 'control' provided by nature for switching off radiation for a short while, permitting us to analyse the response of the atmosphere to a sudden perturbation[9]. More recently, we have made a study that has revealed the presence of turbulent bursts very similar to those observed in the laboratory, and provided new information on their properties.

Another recent study was the formulation of a suitable international tropical reference atmosphere up to 80 km, undertaken at the invitation of COSPAR[10] and now accepted by them.

(5) Rarefied Gas Dynamics

Another line of enquiry that has been pursued over the years in statistical fluid mechanics concerns the solution of the Boltzmann equation in a variety of conditions. An early and surprising result showed that in an entirely *collisionless* flow, gradient transport relations could still apply in some special cases, such as for example free expansion of a gas cloud. Correspondingly, in the opposite limit of near-continuum flow, a theoretical analysis of the structure of the distribution function[11] showed that the very fast molecules are in collisionless flow, even though the slow ones are not, leading to peculiar tails attached to the Maxwellian distribution. A problem in which both limits are important is the structure of a shock wave[12]. Several studies here have established the nature of the solution, including one that in retrospect seems like a very early application of the computer for obtaining solutions to the Boltzmann equation[13].

(6) Other Studies

The familiar elastic string exhibits some very strange phenomena near resonance. My interest in the problem arose from the discovery that the equations then in use for describing such motion were in error; a systematic analysis carried out using singular perturbation methods led to the correct nonlinear equations[14]. These have been used widely, most recently to study the nature of possible chaotic motion in a string. This was indeed one of my original motivations for studying the string, but as it often happens, attention wandered away from chaos in a string to turbulence control around that time.

A second line of studies arose directly from my close involvement in the investigation of the airworthiness of a civilian aircraft. The best method to analyse this problem turned out to be a Monte Carlo simulation of the fleet as it was actually operated, but the basic features of the problem are encountered widely in other fields (e.g. navigation) and led to the formulation of the concept of a stochastic corrective process[15].

(7) Future Directions

The interest in turbulent flows, in technology and in nature, will remain, in particular in the area of control of turbulence and transition modelling. We are setting up experiments to study the dynamics of clouds, which I look upon as a form of turbulence in a heavy two-phase fluid in which nature provides us with beautiful flow visualizations every day!

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R Narasimhan

I am a computer scientist interested in computational modelling of behaviour. Between 1960 and 1970, my principal interests were in the area of modelling visual behaviour. I was one of the early workers in this area to advocate structural models to analyse and describe what is in the visually perceived image. I developed some "grammars" to analyse pictures—mostly alphanumeric characters—and developed recognition systems using these grammars. However, my primary interest was in the early stages of processing of the visual image using parallel-processing techniques. I developed a special language called "PAX" and used it extensively—along with colleagues—to "label" features, regions, etc. in the retinal image. I was doing all this work as part of a group in the University of Illinois (1961-64), where a large-scale attempt was being made to realize in terms of hardware a retinal-image processing system. However, these ideas proved to be too far ahead of what technology could support viably at that time. And the hardware was not brought up to a usable stage. Subsequently, the project was abandoned. One conceptual fallout out of this work was an attempt to characterize some of the visual gestalts through labelling algorithms.

In the last 15 years, my interests have shifted to modelling language behaviour. I have been trying to articulate a computational model that emphasizes pragmatics rather than syntax, i.e., the model approaches language behaviour from a viewpoint that is the reverse of the usual linguistic approach to characterizing languages in terms of their explicitly-stated grammars. My view is that in behaviour modelling one must first of all understand how any form of behaviour is put to use. One should then analyse the structures in the behaviour that enable these kinds of uses. Then one should try to figure out mechanisms that could either build up these structures (if the behaviour is an acquired one) or embody these structures (if the behaviour is a prewired one). The mechanisms should, of course, be consistent with neuro-anatomical and neuro-physiological constraints. These ideas are discussed at length in the book *Modelling language behaviour.*

More recently, I have been doing field studies with a PhD student to test some of the above ideas in the context of first language acquisition. We have been concerned primarily with the language behaviour environment that a child is exposed to in the very early stages (9 months-3 years) of first language acquisition. We have published as a report, the complete corpus of one child's interaction with her parents during this early stage. The corpus runs to several hundred pages in transcription. This study

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is strictly at par with studies of animal behaviour in naturalistic contexts that ethologists carry out. Such ethological studies of language behaviour are essential before we can determine what mechanisms a child comes endowed with which facilitate language behaviour acquistion.

My approach to first language acquisition has very close links with the orality-literacy contrast that has been studied extensively by a large number of specialists from various points of view. Essentially what is being argued is that language behaviour in the oral (i.e., preliterate) mode and that in the literate mode differ in well-definable ways in terms of their pragmatics, syntax and semantics. Hence, the behavioural mechanisms that subserve these two modes of behaviour are also different. What children come genetically endowed with are mechanisms that support language behaviour acquisition and use in the oral mode. The language behaviour that grammarians are typically concerned with is behaviour that relates to the literate mode (i.e., written language and "written" speech).

We approach behaviour modelling from the wrong end if we start by projecting on to it "propositionizing" as the central principle of behaviour: ("rules" in the grammarian's sense belong to this category). As scientists and logicians we are intensely preoccupied with propositionizing. Propositionizable knowledge is the only kind we know how to handle at this stage computationally. However, we would never be able to reconstruct phylogenetic continuity through this approach, since *no other* animal propositionizes. But all animals, we assume, are able to build up a *tacit knowledge* of their worlds. All human-beings also build up a tacit knowledge of vast segments of their own everyday worlds; e.g. all motor skills, most oral behaviour, "recognition" as opposed to "describing", "showing how to do" as opposed to "telling how to do", and so on. The centrality of analogizing in all these as a behavioural principle is a patent fact. A fundamental open problem is providing a computational underpinning to 'analogizing' as a general learning and performance principle in behaviour modelling. Informal language behaviour, I would argue, really belongs here. But language behaviour, once acquired, enables one to build up modes of behaviour involving propositionizing and propositionized knowledge. My current research interests are, therefore, concerned with understanding the oral modes of behaviour and the computational mechanisms that support them.

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Profiles in Scientific Research : Contributions of the Fello Vol. 1 (Indian National Science Academy, New Delhi), 1986.

B R Nijhawan

After graduation in metallurgy in 1936, I won an Indian government scholarship (1938-41) for post-graduate research in metallurgy in UK. I got PhD in metallurgy from the University of Sheffield in 1941 and returned to India in 1942 to organize active metallurgical research and development work during the second world war. I did internationally acclaimed work on armoured plate development and armour failure and related fields. Subsequently, I worked at the National Metallurgical Laboratory (NML), Jamashedpur, of which I was the Director until 1966, when I joined UNIDO, initially at New York and later at Vienna as a Senior Inter-regional Adviser. In this capacity, I have been engaged for almost two decades in the task of advising many of the developing countries in the development of steel industries and establishment of centres of metallurgical technologies/iron and steel research centres/central metallurgical research and development institutes.

My most prominent work at NML related to "austenitic grain size control of steel", a subject introduced in India by me. In formulating the aluminium solution theory among the host of theories advocated earlier and while investigating it at length. I found it unable to answer and satisfy some characteristics of grain growth inhibition. The work was acclaimed internationally; however, arising from the untenability of the aluminium solution theory in explaining some of the typical characteristics of austenitic grain growth inhibition in steels and related aspects of abnormality in steels, my attention gradually veered towards the role of aluminium nitride in austenitic grain growth inhibition in steels and abnormality characteristics on which sustained research was carried out by me and my colleagues; the results of this work today find almost universal acceptance in the metallurgical world.

During the second world war, I carried out detailed and systematic investigations on failed Armoured Carriers during storage and war conditions in African theatres which led to the successful elimination of their disastrous failures. This single piece of Research and Development won me distinguished recognition from the then British authorities while the South African R & D Centres failed to deliver the goods.

Another major line of work started by me at NML related to the development of substitute families of alloys in which such metals as were not available indigenously (e.g. nickel, cobalt, tungsten, molybdenum, etc.) were to be totally or partly replaced by such metals as were available in India (e.g. chromium, manganese, aluminium, etc.); most notable among the family of substitute alloys based

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on indigenous alloying elements (metals) was the Research and Development work conducted under my leadership on nickel-free austenitic stainless steels based on nickel, chromium, manganese and nitrogen quaternary system in place of nickel-chromium austenitic stainless steels; this work was industrially carried out by me in Belgium and received international recognition and awards besides global grant of patents in UK, FRG, France and other western countries.

Parallel fields of substitution related to the substitution of zinc by aluminium. The process of aluminizing of steel was thus successfully developed, both for steel wire and sheets.

Another major field of activity was Indian foundry sands and bonding materials. An active research group was formed by me to investigate Indian foundry sands on an all-India basis and its work resulted in a valuable monograph on Indian foundry sands.

Under the advice of two international pillars of metallurgical research—Sir Charles F Goodeve, FRS (UK) and Prof. I P Bardin (USSR)—with whom I came in close contact in 1957-58, I launched the programme of setting up at NML integrated pilot plants for batch and continuous operations on important metallurgical themes of topical interest to the mineral and metallurgical industries in India. In particular, the low shaft furnace pilot plant set up represents a major highlight of metallurgical research advancement anywhere. The development of alternative processes of iron production with indigenous raw materials regionally dispersed in different parts of India, represents a major field of my metallurgical research interests; distinct contributions of our group in this area helped to put NML on the research map of the metallurgical world.

In line with my work during the second world war on the development of armour for the Armoured Carriers, much later, during 1966, I investigated exhaustively the 80 tons Patton Tank crippled during the 1965 Indo-Pakistan war; this was a major breakthrough for Indian tank industry.

Another outstanding achievement was the setting up of the integrated mineral beneficiation plant, the work on which has been chiefly responsible for the implementation of the mineral beneficiation flowsheets, agglomeration techniques and ore-dressing and upgrading cycles developed at NML by the Indian steel plants. The integrated ferro-alloy pilot plant has through pilot plant results on ferro-alloy production, helped not only in meeting urgent needs in part of the defence and ordnance plants, but also of the metal industry. The entire work on processing and beneficiation of iron ores for the Bokaro Steel Plant was guided by me under a USSR contract as also for Tata Iron and Steel Co. and later for all the steel plants in India; this work and its results represented a major breakthrough for the Indian steel industry and was widely acclaimed by Gypromez (USSR) as of high technical standard and by the Chairman of Tata Iron and Steel Company, Mr J R D Tata at his annual published statement to the Board of Directors and the Shareholders.

I have been the recipient of many national and international awards—Padma Shri (1958), S S Bhatnagar prize (1965), gold medal and hony membership of the Japanese Iron and Steel Institute, hony vice-presidentship of the Iron and Steel Institute, UK, hony membership of the French Metallurgical Society, hony membership of Austrian Foundry Society, Presidentship of the Indian Institute of Metals, Institute of Indian Foundrymen and gold medal of the National Metallurgical Laboratory, Jamshedpur (1975). More recently, in January 1986, I received an International Distinguished Award from the Polish Federation of Metallurgists of the Polish Government for my services to the developing countries during my work at UNIDO covering almost two decades in the fields of metallurgical industries and research and development work in multiple metallurgical fields leading to the establishment, in many cases at the Greenfield sites, of 25 centres of Metallurgical Technologies, Iron and Steel Research Centres and Central Metallurgical Research and Development Centres, all of which are now fully operational and substantially contributing to the substantive growth of metallurgical industries throughout the developing world under the United Nations Industrial Development Organization based on my sustained work spread over the last two decades.

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M A Pai

With the increasing interconnection within a power grid and among regional grids, the stability of a power system under disturbed conditions is a major concern for both planners and operators of a utility. The tools are basically good analytical models and efficient computer algorithms. If instability is foreseen for certain eventualities, design of proper control mechanisms is necessary. Pai pioneerd the use of direct method of Lyapunov, which is well known in control theory, for power system applications. It basically enables the planner and operator to examine a number of contingencies very quickly to see if the system will be stable. He has also proposed corrective scheduling algorithms. The books "*Computer techniques in power system analysis*" (Tata-McGraw Hill) and "*Power system stability by direct method of Lyapunov*" (N. Holland Publishing Co.) have served as key references in this area all over the world. Within the country, he pioneered the in-house use of computers for planning studies by the U.P. State Electricity Board by creating a U.P.S.E.B. computer cell at the Indian Institute of Technology, Kanpur and developing the necessary computer software. It is being updated constantly. His present interests are in two areas: (i) Techniques for dynamic security assessment, and (ii) power system stabilization. In the former, he is trying to implement energy or Lyapunov function methods into a viable tool for the operators to help them maintain the system in a secure state. In the area of power system stabilization, suppression of low frequency oscillations between large generation sites (superthermal stations) and remote load centres or between regional grids is very necessary. These problems require the use of power system stabilizers whose design and location in a large scale power system are important issues. Pai's research has led to the development of new techniques in the time-domain for this purpose.

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Rajinder Kumar

The main area of my research has been the analysis of multiphase systems. Special attention has been paid to the problems of fluid-liquid dispersion, foam bed contacting, and coalescence and breakage of drops in stirred dispersions. It has been possible, through this work, to improve our understanding of these phenomena and to develop mathematical models involving them.

(1) Fluid-Liquid Dispersion from Submerged Nozzles

Earlier, the phenomena of bubble and drop formation at single submerged orifices were being treated separately. Further, for bubble formation, the results reported in literature as to the effect of different variables were so divergent and contradictory that their resolution seemed unlikely. Through the two-stage model[1-4], it was possible not only to explain why earlier investigators had obtained contradictory results, but also to predict the actual effects quantitatively. The next step was the development of a unified theory, which could explain both bubble and drop formation through a single set of equations[5]. This model has been tested widely for many divergent systems like industrially relevant non-Newtonian liquids and fluidized beds. The two-stage model was then combined with geometric considerations, drainage between bubbles, and new models were developed for the prediction of drop or bubble sizes in complex distributors like sieve plates[6] and sintered disks[7]. The model for sintered disks is the only one available in literature till now.

The unified model has recently been extended to drop formation in pulsed columns when they operate in mixer settler regime. The main feature of pulsed column is that the rate of liquid flow through the orifices is variable. The model correctly predicts both the number of drops and the size of each drop formed. To make the model more general, it has been extended to non-Newtonian continuous phases also and has been tested successfully.

The model has been further extended to actual pulsed sieve plates containing many holes.

Using similar ideas, it has been possible to propose new models for pneumatic atomization[8] and nucleate boiling[9]. The model on nucleate boiling simultaneously predicts the bubble growth history and the final vapour bubble diameter.

(2) Foam Bed Contactors

For the past few years, investigations have been carried out on the analysis of foam bed contactors, which offer some special advantages for pollution abatement and as separation devices. These

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contactors are rather complex and the work done on them hitherto had been understandably empirical in nature. By considering the foam to be made up of equisized dodecahedral bubbles, a model has been developed[10] which can predict the performance of this contactor. The model has been further tested recently for an industrially relevant reaction, viz., the oxidation of sodium sulphide[11]. The model has also been extended to include the analysis of three-phase foam beds. The third phase could be a solid catalyst, another liquid in the form of an emulsion, or a dissolving solid reactant. A model of foam bed reactor taking surface resistance to mass transfer into account has also been developed and tested.

In all the above models, one of the parameters required is liquid hold-up in the foam bed as a function of height. This was hitherto determined experimentally and the values obtained were used in the model. Recently, models have been developed for the prediction of liquid hold-up in both semi-batch[12] and cocurrent[13] foam columns, by assigning separate roles to the nearly vertical and nearly horizontal plateau borders, and also by taking surface mobility into account during drainage through Plateau borders[14] and films. A new criterion has also been proposed and used for modelling the exit foam density in cocurrent foam columns.

(3) Coalescence and Breakage of Drops in Stirred Dispersions

Stirred vessels, though commonly used in industry, are very poorly understood even when no dispersed phase is present. When a dispersed phase is present, the transport processes get influenced significantly by the breakage and coalescence phenomena involving dispersed phase particles. The phenomenon of coalescence of drops in stirred dispersions has been analysed recently by treating the coalescence as being due to stochastic variation of force fluctuations which are responsible for drainage of liquid between drops. The same fluctuations result in either coalescence or separation of drops which are in collisional contact. These models explain some of the interesting observations about coalescence reported in literature.

A new model[15] has been proposed recently for breakage of viscous as well as non-Newtonian liquids in stirred vessels. This model considers, through a Voigt model, the simultaneous effect of surface tension and flow in the drop during its deformation. The restoring force due to surface tension has been assumed to pass through a maximum. The model gives the maximum stable drop size in the stirred vessel as a function of various operating parameters and physical properties of the system. The model is found to be applicable over wide ranges of variables and rheological parameters.

The effect of an immiscible liquid phase on the gas-liquid interfacial area in a stirred vessel has been explained recently[16]. As the organic phase fraction increases, the area passes through a maximum. The behaviour has been explained on the basis of the degree of prevention of bubble coalescence by the immiscible phase droplets.

(4) Proposed Work

It is proposed to investigate some hitherto unexplored aspects of foam bed contactors. These include jet impingement and flow reversal on foam beds and their analysis for particulate and gas pollution control, gas separation through the use of foam beds, concentration of cells and surface active materials, recirculation in foam columns and analysis of foam bed reactor for instantaneous and complex reactions.

Major thrust of effort will be in the area of stirred dispersions. Typical problems to be tackled in this field include coalescence models, breakage of viscoelastic liquids and prediction of their non-breakage conditions, maximum drop size predictions for dispersion of liquid membranes, and study of the phenomenon of inversion in stirred vessels.

The whole area of emulsion regime performance of pulsed columns is planned to be studied.

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H Rakshit

My early work related to propagation of wireless waves and ionosphere; three-phase R-C oscillator; and applications of the principle of delayed coincidence.

The first important work undertaken was survey of radio field strength around the Calcutta broadcasting transmitter by measuring resonance voltage across a portable loop aerial. A two-valve receiver built and calibrated in the laboratory as a voltmeter was used for the purpose. The results obtained[1] showed that attenuation of the waves over land is much greater than over water and that local shadows due to elevated steel structures are wiped out at larger distances due to energy coming from other portions of the wave front.

The next problem to be investigated was propagation in the Heaviside-Kennelly or "E" layer. Natural fading was studied and the effective layer height measured by the angle of incidence method of Appleton and Barbnett. Observations were made with medium wave signals from the Calcutta broadcasting transmitter ($\lambda = 370.4$ m); the receiving site at a distance of 121 km was so selected that the downcoming waves suffered only one deflection from the E-layer. One vertical aerial and one large loop aerial were used and each was associated with a receiver. The details of observation were reported[2]. The lowest height was found nearabout sunset and increased gradually with the progress of night up to the end of the observation (11 pm). The intensity and nature of fading with the progress of night varied from night to night.

It was generally recognized that there are two distinct ionized layers at different heights in the upper atmosphere. The lower E-layer is responsible for the propagation of long and medium waves, while the upper F-layer carries short wave signals over long distances. After studying the E-layer, it was decided to study the F-layer with different wavelengths and at different hours of the day and night by the group-retardation or pulse method, which is very versatile.

Some preliminary observations were carried out in collaboration with Prof. Mitra[3]. The transmitting aerial was of the inverted L type with a counterpoise for work on 50 and 80 m and horizontal dipole for 42 and 75 m. The receiving aerial for 50 and 80 m was of the outdoor inverted L type with a relatively long horizontal portion, while for 42 and 75 m it was a single turn square loop. The transmitter was built and located in the laboratory, while the receiver, similarly built, was located at a distance of 3.5 km in the beginning. For later observations, the receiving equipment was carried in a small bus and records were obtained at various short distances and in different directions

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from the transmitter. Within the range of wavelength studied (42-80 m), no marked height variation was observed; of course, diurnal and seasonal variations were noted. The multiplicity of echoes, mostly observed during sunset periods, was very interesting. A constant interval between consecutive echoes on the CRO screen indicated that these are due to multiple reflection between earth and the ionized layer.

Considering the importance of such observations and measurements, I continued the work and participated in the Polar Year (1932-33) programme of observations on upper atmospheric ionization after making some improvements in the transmitting and receiving systems[4]. For these observations on $\lambda = 75$ m, the receiving loop aerial was permanently located at a distance of 7 km from the transmitter.

Observations on diurnal and seasonal variations of height showed that the echoes are abnormally strong during sunrise and sunset periods. Explanation of these abnormalities necessitated a quantitative estimate of echo field strength.

The receiver comprising hf, lf and detector stages was calibrated in a novel way. A continuous wave oscillator was interrupted by a tuning fork at the same rate as the transmitted pulses. The output circuit was completed through a Hull cylinder and a thermal milliammeter. A continuous current was made to flow through the wire by short circuiting the tuning fork system. The receiver input was the voltage developed across a portion of the axial wire of the cylinder. Knowing the current and the impedance of the wire utilized, the input voltage was calculated. The amplitudes of the pulses seen on the CRO screen, when interrupted currents flowed through the wire, were recorded for different input voltages and thus the receiver was calibrated.

Measurement of the ionization content of the upper atmosphere was also made towards the end of the Polar Year. The results showed that the diurnal variation of ion content agrees fairly well with Chapman's theory based on the assumption of a beam of incident solar monochromatic ionizing radiation. This is for an average day, but there were days when this agreement did not hold.

The depth of penetration of radio waves inside the conducting layer was also measured to get an idea of the gradient of ionic density. This was done from observations of magnetic splitting of the waves. Ordinarily, a single transmitted pulse is split up by the earth's magnetic field, on entering the ionized region, into two components—ordinary and extraordinary—the extraordinary component reaching the earth earlier than the ordinary component. The time interval depends on the gradient of ionization; the greater the gradient the shorter is the interval. From a knowledge of this interval and the average group velocity of the waves in the region, we can calculate the depth of penetration.

Splitting has been found to be more frequent and the time interval much longer for F-layer reflection than E-layer. With the progress of night, the average F-layer height increases and so also the time interval, leading to a reduced ionization gradient.

Wireless echoes at the transmitter were first recorded by Mitra and Rakshit[5].

Observations on the ionosphere by the group-retardation method showed that intensities and number of echoes diminish as the receiver is brought near the transmitter. One of the causes is the enormous strength of the direct ground signal as compared with that of the echoes. There is another factor which becomes important at very short distances from the transmitter. We pointed out that the transmitting aerial itself collects energy from the reflected wave from over a large area and the much less efficient receiving aerial gets insufficient energy for recording echoes. By using the same aerial for transmission and reception, the echoes were recorded right at the transmitter. This provided the basic idea for radar.

Studies on distribution of the constituent gases in the upper atmosphere became necessary when it was found in Calcutta and elsewhere that meteoric showers and corresponding increases in ionization in the E_1 and E_2 regions sometimes produce bursts of radio signal intensity of short duration and sometimes cause great reduction in intensity due to absorption. Prof. Mitra and I took up the work and the results[6] were based on our available knowledge of $T = 100°K$ at 80 km with a linear increase of 4°K per km with height and pressure $= 10^{-3}$ mm at 100 km with the same atmospheric composition of N_2 and O_2 near the ground.

The studies were continued by me specially to ascertain the distribution of O_2 and O in the upper atmosphere, O_2 being dissociated in the region by absorption of solar ultraviolet radiation. I found[7] that the density of O_2 decreases very rapidly with height above 100 km, while that of O, which is almost zero at 80 km, increases rapidly with height, attains a maximum at about 105 km, and then decreases gradually. The transition layer in which O_2 decreases rapidly plays an extremely important part in the production of the E-layer.

Three-phase R-C oscillator for radio and audio frequencies: Rakshit and Bhattacharyya[8] have shown that the conventional circuit of a three-phase R-C oscillator with components selected for af oscillations invariably generates high radio frequencies of the value $\sqrt{3}/2\pi RC$ due to unavoidable stray and interelectrode capacitances. The circuit can produce audio frequencies only after some modifications are made. Under certain favourable conditions, both the modes may be maintained simultaneously. It has also been pointed out that the oscillator can generate FM oscillations on varying the tuning resistance of one of the stages by the modulating voltage. A simple method would be to shunt one of the oscillator valves by a triode having the modulating voltage on its grid.

Rakshit and Sarkar[9] made detailed studies on the production of FM. It was found that faithful modulation without appreciable amplitude modulation can be had under proper adjustments. Their experimental results proved this for a 1 Mc/s carrier.

Rakshit and Mallik[10] found that when the load resistances are ≈ 1000 ohms or more, variation of anode impedance of the modulating triode can produce linear frequency variation much greater than what is needed for wide-band FM. For smaller resistances such super-wide band FM requires some changes in the circuit.

Rakshit and Mallik made further critical studies on the three-phase oscillator. They found that for the simple oscillator using high-mu pentodes like 6AC7 ($g \approx 9$ ma/V), minimum value of load resistance comes to ≈ 220 ohms. In actual practice, oscillations were produced with much smaller resistances wound on thin mica cards due to small inductances associated with them[11]. They also found[12] that the cathode circuit may be represented by a small resistance in series with a reactance. A capacitative cathode causes an increase, while an inductive cathode causes a decrease in frequency from the "normal" value with resistive anode and cathode.

The case of inductive load resistance was also studied and verified experimentally[13]. The effect of reactive cathode was found to be same as with resistive anode, but resistive cathode gave an increase over a "normal" value up to a certain value of inductance; thereafter, the frequency went on decreasing.

Applications of the Principle of Delayed Coincidences

Rakshit and Chatterjee[14] described a technique for measuring ionospheric heights by the method of delayed coincidence having accuracy much greater than that attained earlier. Trigger pulses having frequency 50 simultaneously actuate two phantastron delay circuits. One produces a large square wave modulating voltage of suitable duration and delayed from the trigger to an adjustable extent. The modulating voltage makes the transmitter generate rf pulses. The second phantastron excited by the same triggers another pulse of variable delay, which, in turn, triggers a blocking oscillator, giving a positive pulse of a short duration. This is then inverted and finally fed to the coincidence system along with the negative pulses from radio receiver-ground pulse and the echoes. Height has been measured with an accuracy of ± 0.1 km, but further improvement is possible.

Rakshit and Mukherjee[15] described an electronic torquemeter involving measurement of small time intervals by the coincidence technique. A shaft transmitting mechanical power is subjected to a torque or twist of magnitude dependent upon the transmitted power. Two sharp pulses of voltage are produced across two magnetic pick-up coils by two blades of magnetic material fixed to the shaft at a known separation. Initially, the free-running shaft produces two pulses which occur simultaneously, but when it transmits power the pulses are separated by a small time interval, which is measured by the coincidence technique.

Working on this principle, Mukherjee and Rakshit[16] designed and constructed a remote control electronic torquemeter. The shaft unit is fixed between the power generating machine and the load. The twist undergone by the shaft when power is transmitted is measured in terms of the time interval and r p m of the shaft. These two quantities can be measured from a remote distance with sufficient accuracy. The performance of the torquemeter developed has been checked by comparison method and it has been found suitable for both high and low speeds.

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A Ramachandran

Heat transfer is a branch of the broad field of engineering sciences encompassing solid mechanics, fluid mechanics and thermodynamics that came to be recognized as essential links in the knowledge that enables scientific principles to be adapted to yield technological devices for human development. The science of heat transfer concerns analysis of systems that exchange energy by virtue of temperature differences, while the technology of heat transfer deals with the thermal design, development and fabrication of such systems. It is no exaggeration that there is hardly a branch of technology that does not involve, directly or indirectly, temperature inequality and, therefore, heat transfer—be it in mechanical, electrical, electronic, chemical, metallurgical or aerospace engineering discipline. It was only in the late 40's and early 50's that the vital importance of this subject gave a quantum push to research in developed countries. During this time, very little work was being done in this field in India, since there were hardly any graduate programmes in engineering, leave alone in the special area of heat transfer. Against this background, I joined as the first faculty member of the newly established graduate programme in Mechanical Engineering at the Indian Institute of Science, Bangalore, in 1950 on my return from USA, where I obtained my doctorate in heat transfer under the late Max Jocob and George A Hawkins. It was a challenge and an opportunity. During the next 17 years, I was engaged in the task of building a school of research in heat transfer which attracted a number of visiting scholars and professors. Since India was just embarking on a major industrialization programme and concentrating on heavy basic industries during the second plan period, such as steel plants and foundry-forge units, it was felt that applied research in heat transfer should be directed towards practical systems in production technology. Accordingly, a major programme was initiated in the graduate division of foundry engineering on the study of mechanical properties, thermal properties and solidification of castings. The effects of many variables, such as mould ratio, chills, mould materials, the composition of alloys and the moulding methods on the thermal characteristics and thereby the mechanical properites of castings were investigated[1–4]

Another important area of heat transfer research activity during this period was thermal power plants. Use of lignite for power generation, pool-boiling heat transfer, combustion stabilization, high temperature properties of metals in the design of modern power plants and the thermal design of heat exchangers were some of the problems investigated[5–7] On the basic research side, a major effort was

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undertaken in the area of thermophysical properties of metals and non-metals, gases and vapours, including refrigerants[8–10]. Fundamental problems of industrial significance in convective heat transfer, such as the influence of vibration, thermal entry length effects in concentric annuli, and hydrodynamics in circular and non-circular ducts were studied[11–13]. Work on these topics initiated in India for the first time during this period continues to be of topical importance even at the international level. The school of heat transfer research had a multiplier effect over the past two decades through its graduates and scholars continuing research in this field at their own institutions.

After taking over as the Director of Indian Institute of Technology (IIT), Madras, in 1967, I gave a major thrust to research there by encouraging basic and applied research in all fields of science and engineering. In particular, in the area of heat transfer, refrigeration and air conditioning a new school of research was established under my direction. In the later half of the 60's, the results of the green revolution were becoming evident as were the effects of enhanced power generation and electronic industry. It was, therefore, essential that problems of heat transfer related to food products, such as refrigeration, freeze-drying and drying be investigated. It was also important for a tropical country like India that indigenous expertise be developed in research competence in the field of air-conditioning. Further, the sources of energy for thermal power generation in the short and medium ranges were likely to be coal and nuclear. Research was, therefore, launched into the latest technologies for coal utilization, such as fluidized bed combustion and heat transfer and cooling of electrical machinery. The research school also initiated work on cooling of electronic devices, an area of great importance in view of the impending electronic revolution in the country.

In the area of food products, heat and mass transfer characteristics of food products in air cooling, storing and freeze-drying were investigated. Several analytical and experimental studies were undertaken to obtain charts which could be used in practice for predicting time-temperature characteristics during precooling and preserving of food products[14–16] Work on heat transfer in and combustion of coal, in particular, lignite, using the technology based on atmospheric fluidized bed process was initiated in 1971. Fundamental hydrodynamic and heat transfer were investigated analytically as well as experimentally and the problem of development of a fluidized bed boiler with optimum tube-bundle internals was taken up. As early as 1971, an industrial research project was taken up under my guidance to investigate the thermal design of large turbogenerators. This problem is of great industrial importance in view of the trend in the power industry to go in for large-sized thermal units of 500 MW and above. Since the thermal design of the generator is invariably the limiting factor in the attainment of self-reliance in this field, a pioneering effort was undertaken in 1971 and through research collaboration with the BHEL, R&D continued over subsequent years. Cooling of electronic equipment was another new area of research initiated during 1971-73 at IIT, Madras. Revolutionary developments in micro-miniaturization of electronic equipment in the entertainment, communications and defence industries called for new, innovative and effective methods of transferring dissipated energy in the electronic devices to maintain the system within strict temperture limits, thus ensuring reliable performance. Natural, evaporative and cryogenic cooling techniques have been and continue to be investigated at the school of research, IIT, Madras.

After I assumed charge as Secretary in the Department of Science and Technology (DST), Government of India, in 1973, a research and development programme in energy was initiated under my supervision, particularly in the solar, thermal and photovoltaic and other renewable energy sources. Basic and applied research on the exploitation of new and renewable sources of energy has been given great push in the country during the past decade. In collaboration with BARC and BHEL, DST initiated a major programme on power generation through the magneto-hydrodynamic process, resulting in the commissioning of the 5 MW pilot magnetohydrodynamic power plant in Tiruchi in 1985.

Since 1978, I have been an Under-Secretary General of the United Nations and Executive Director of United Nations Centre for Human Settlements—UNCHS (Habitat). At the centre, several energy-related projects have been implemented or are on-going under my overall guidance. They include: energy requirements and energy conservation in human settlements, land use in relation to solar energy, passive heating and cooling systems in human settlements, solar energy design data for use by architects, and energy generation utilizing urban waste.

The thrust of future research and development work would be on the development of new technologies for renewable sources as they relate to specific economic sectors in human settlements, such as domestic, agriculture and transportation. It is evident that the status of certain technologies of these new sources is already commercial, whereas that of some others is at the experimental and demonstration stages. Efforts should be directed towards technological research and development that would render solar thermal systems for cold storage and refrigeration and power generation, wind and hydro systems for power, biomass, agricultural and forest residues and other wastes for heat or power or liquid transport fuels viable.

The energy programme of UNCHS (Habitat) envisages future activities to encompass specific areas, viz., settlement and energy policies, energy-efficient spatial patterns in human settlements, energy conservation in buildings through pilot and demonstration projects.

In designing integrated settlement policies and planning, special attention should be paid to the development of spatial policies and land-use planning aimed at conserving energy; appropriate methodologies, codes, standards, guidelines and evaluation methods for the effective utilization of new and renewable sources of energy in various aspects of human settlements; a reliable database for information on energy requirements and consumption in both urban and rural settlements; and policies for promoting continuous interaction and dialogue between decision-makers, professionals and the public at large in respect of decisions and programmes for the utilization of new and renewable sources of energy.

Energy-efficient spatial patterns in human settlements emphasize that the spatial patterns of existing and new settlements should be designed to conserve energy and to make greater use of new and renewable sources of energy. This may be achieved by undertaking urban renewal, conservation and rehabilitation programmes with a view to reducing the use of energy-intensive modes of transport, promoting mixed land-use patterns, as opposed to the traditional approach of separating residential, commercial and industrial zones, developing optimal energy networks and district energy systems and making efficient use of agriculture residues, biogas, solar energy, etc., to meet the energy needs of rural settlements.

An important aspect of the problem of energy for physical infrastructure and service in human settlements is that physical infrastructure should be so designed or redesigned as to conserve energy, to reduce its costs and to make greater use of new and renewable energy sources. This may be achieved by designing energy-efficient transportation systems; promoting measures to reduce energy consumption in water and sewage treatment and in the collection and disposal of solid waste; recycling; promoting the use of solar energy; and ensuring the efficient management of municipal wastes that are net producers of energy.

In the area of energy and building, applied research would be undertaken to encourage the design, construction and maintenance of buildings and to choose building materials and technologies in such a manner as to promote greater use of new and renewable sources of energy. To achieve this, special emphasis should be placed on the development of passive design concepts which take into account variations in energy consumption due to the height, shape and orientation of buildings and which involve the natural principles of heat transfer in buildings; retro-fitting of the existing building stock to permit greater use of new and renewable sources of energy; development of hybrid/integrated systems for space conditioning involving the use of new and renewable sources of energy; promotion of the production and use of energy-efficient building materials and technologies, with emphasis on the shelter needs of the poorest segments of the population in rural and urban areas.

There are, of course, no universal solutions to the problem of meeting the energy needs of human settlements because of geographical and climatic variations and socio-economic and cultural differences in settlement patterns. Known solutions need to be adapted, tested and promoted through pilot and demonstration projects in a variety of settlement situations. Therefore, pilot projects should be implemented in a variety of climatic conditions, in settlements of different sizes and in a variety of socio-economic situations in the urban and rural areas of various regions in order to promote the use of new and renewable sources of energy.

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P Ramachandrarao

Casting of metals is an ancient art. However, the scientific principles underlying solidification of metals and alloys have been developed and understood only in the last few decades. It is, therefore, not surprising that experiments aimed at cooling liquid metals at the phenomenal rates of 10^6-10^{10}K s^{-1} were conceived and carried out only in the early sixties of this century. The pioneering effort in this area was due to Prof. Pol Duwez of the California Institute of Technology, Pasadena, USA. Duwez and his coworkers demonstrated that solidification at such large cooling rates can result in the formation of metastable solid solutions and intermediate phases and yield metallic glasses. These results gave considerable impetus to alloy development and opened up a new and fascinating field for physical metallurgists. The group at the Department of Metallurgical Engineering, Banaras Hindu University, was quick in realizing the importance of such studies and was among the first few groups to undertake such studies.

Rapid solidification of alloys is achieved through the production of thin (< 40 μm) layers of liquid metal over highly conducting substrates. In the early years of development, the objective was attained by shooting a small quantity of liquid alloy, with the aid of a shock tube, onto a ski-slope substrate. The technique has come to be known as the "gun" technique. Alternatively, in the piston-and-anvil technique, a freely falling droplet is caught between a stationary anvil and a fast moving piston. At Varanasi, these two techniques were combined to yield large (7-8 cm diam) discs of rapidly solidified alloys for physical and mechanical property determinations. Working in association with the group at the University of Sussex, Brighton, UK, Ramachandrarao was able to exploit the high thermal conductivity of diamond at sub-zero tempertures and generated the highest cooling rates known todate. The collaborative research also demonstrated, for the first time, the usefulness of lasers in generating metastable intermediate phases on the surface of irradiated alloys. The advent of the melt spinning technique has enabled the production and technological exploitation of metallic glass tapes. The development of the planar flow casting technique at Allied Chemicals, USA, has made the production of broad tapes a reality. These techniques have also been established at Varanasi under a nationally coordinated project on metallic glasses for the development of Fe-B and Fe-Si-B alloys for use in power transformers.

Early years of rapid solidification studies at Varanasi were devoted to a study of

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aluminium alloys. The choice of aluminium was dictated by the abundance of this metal in the country. Ramachandrarao and his group have investigated several binary systems based on aluminium and having bismuth, cadmium, copper, germanium, indium, lead, nickel, platinum and silver. The studies showed that extension of solid solubility limits of these solutes can be achieved and that several new metastable intermediate phases can form in these alloys. In a few cases, glass formation was also detected. Besides aluminium alloys, a few alloys based on noble metals were also studied and characterized. The thermal stability of the rapidly solidified alloys and their ageing behaviour also received attention and the decomposition schemes of many of these alloys were drawn up. Among the results achieved, the production of grain sizes of the order of 100 Å, formation of metastable prototype phases, such as Al_3Cu_2, novel vacancy ordered phases, detection of twinned dendrites, etc,, deserve mention.

Experience gained through the study of rapidly solidified alloys very soon demonstrated that a factor of paramount importance is the degree of undercooling achieved. Attempts were, therefore, made to undercool 30-50 g quantities of alloys by the well known glass-slap technique. Towards this end, silver-germanium and cadmium-zinc alloys were selected and treated and used in making window glass and $ZnCl_2$ glass slaps respectively It was demonstrated that undercooling gives metastable solid solutions in both these alloys, the contents of alloying elements in solution being comparable or superior to those observed in rapid solidification experiments. The glass-slag technique is not universal in its applicability owing to difficulties in selecting non-reactive glass for every alloy system studied. To overcome part of the problem, the group adapted the technique wherein liquid droplets are entrapped in the solid metal matrix by holding in the mushy, i.e., liquid + solid region and repeatedly cycling them between the holding and room temperatures. Spectacular successes were achieved by this route by way of producing metastable phases in aluminium germanium alloys and glassy phases in magnesium-zinc alloys. Such studies are still underway on several monotectic alloys. The results obtained by the group on undercooling have formed the basis of the materials science experiment conducted in space by Squadron Leader Rakesh Sharma during the Indo-Soviet Joint Space Mission of April 1984.

The many faceted results obtained through rapid solidification and undercooling require a sound explanation in terms of thermodynamics and energetics. Ramachandrarao and coworkers have striven hard to develop such models. The earliest such attempt showed that a direct correlation exists between the peaks in partial excess entropy plots against composition and metastable phase formation. Subsequent studies were aimed at establishing the existence of clusters in the liquid state by fitting the observed free energy and enthalpy values to the regular associated solution model for compound forming melts. The method was extended to include explanations for glass forming tendency as well.

Glass formation was also predicted through several alternative models based on the calculation of either the volume changes that accompany mixing in the liquid state or the hole concentration in the liquid. The former approach predicted the composition ranges suitable for glass formation, while the latter was able to predict the critical cooling rate for glass formation, the magnitude of property changes at glass transition, the viscous behaviour of undercooled melts and the temperature dependence of the free energy of the undercooled melt with respect to the solid state. It can also predict the ideal Kauzmann glass transition temperature with remarkable accuracy from the heat capacity and entropy differences between the liquid and solid phases at the melting temperature.

Towards the end of 1984, a remarkable observation was made in rapidly solidified aluminium-manganese alloys by the group at the National Bureau of Standards, USA. They detected crystals with five-fold rotational symmetry, which is incompatible with translational symmetry. These crystals, since christened quasi-crystals, have generated great enthusiasm among solid state physicists and physical metallurgists and almost all the initial results were obtained on aluminium-managanese alloys. Ramachandrarao and Sastry showed that such crystals can be anticipated on the basis of the crystal structure of equilibrium compounds; they synthesized quasi-crystals by rapidly solidifying Al-Mg-Zn alloy. Several other similar alloys have since been studied by the Varanasi group and their results have provided many more alloys for investigation.

Rapid solidification is fast growing into a technology. Several products of this young area of research have already found industrial and commercial applications. Major applications are foreseen in the aerospace, electrical and electronic industries. It is hoped that the expertise generated at the Banaras Hindu University, Varanasi, will prove useful in the development of indigenous technology.

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P Rama Rao

Rama Rao's research contributions are principally in two areas of physical metallurgy: (i) X-ray diffraction study of structural imperfections in metallic materials; and (ii) correlation of mechanical behaviour (tensile, creep, fatigue and fracture characteristics) with the microstructure of metals and alloys.

Rao's X-ray studies on imperfect metallic structures had the three-fold objective of innovating methods for the analysis of X-ray diffuse scattering for eliciting information on parameters (domain size and lattice strain), reflecting dislocation (line defect) densities, and distribution and the type and extent of stacking faults (planar defects). His pioneering work has been on close-packed structures [e.g., double hexagonal close-packed (DHCP)] hitherto not studied and on potentially significant systems belonging to the well-known face centred cubic (FCC) and hexagonal close-packed (HCP) structures.

In the area of new methods of analysis of X-ray line broadening, Rao's contributions include development of a simple method of analysis utilizing integral breadths; formulation of a modified Fourier technique requiring only single diffraction lines where practical limitations preclude the use of multiple orders of X-ray reflections, as required in the well-known Warren-Averbach method; suggestion of a new procedure based on elastic anisotropy for the separation of stacking fault and domain size components when Warren-Averbach Fourier transforms are used for the analysis of X-ray diffraction effects in body-centred cubic (BCC) structures; and advancing of an interpretation of X-ray line shifts due to stacking faults from purely geometrical considerations.

Rao and coworkers postulated, for the first time, possible fault configurations in DHCP crystals. X-ray diffraction effects for these faults in the DHCP structure were subsequently evaluated by one of his colleagues and the experimental work on a DHCP Au-Cd-In alloy provided comprehensive evidence for all the predicted X-ray diffraction effects, leading to complete evaluation of seven fault probabilities. Development of crystal structures with a larger number of layers in the stacking sequence, akin to polytypism, was also observed for the first time on splat-quenching the DHCP Au-Cd-In alloy from the liquid state.

Several significantly original experimental results have been derived by Rao in the course of X-ray measurements on a variety of metals and alloys belonging to the FCC and HCP classes. The observation and separation of extrinsic stacking fault contribution in Pd, systematic elucidation of the effects of

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electron concentration and solute-solvent valence difference on propensity to faulting in a series of binary alloys with the discovery of the heaviest faulting ever noted for alloy systems, observation of a strain-induced FCC → HCP transformation, striking evidence for d-band contribution to stacking fault energy, and the novel extension of some of these concepts with new measurements on FCC ternary alloys, binary HCP alloys and more complex materials, studies on the effect of thermal and mechanical treatments on faulting, and the first measurements of faulting in liquisol-quenched materials, are illustrative of Rao's endeavours in this field.

Significant contributions of Rao with regard to the correlation of mechanical properties with microstructure concern high strain fatigue at ambient and elevated temperatures, power-law as well as viscous creep, creep fracture, Portevin-Le Chatelier effect and solid particle erosion, besides novel studies pertaining to tensile deformation and fracture characteristics of carefully chosen alloys. Deformation as well as fracture mechanism maps, based on experimental observations, have been constructed for metals and alloys of technological importance.

Remarkable effects of grain boundary mobility on high strain fatigue (HSF) characteristics at elevated temperatures were shown by Rao's group from their work on Al and Zn. The effect of tensile prestrain on HSF of an indigenously produced Nb stabilized high strength low alloy steel, the impact of high strain rate sensitivity index of flow stress on HSF of a superplastic bronze, the influence of varying microstructure on HSF of Concorde Al Alloy RR 58 at ambient as well as elevated tempertures, the effects of ferrite-martensite microstructural morphology and the volume fraction of martensite on HSF of dual phase steel are striking research results on important new alloys. The observation of two-stage cyclic work hardening and its bearing on two-slope Coffin-Manson behaviour in dual phase steel treated to develop inhomogeneous microstructures are noteworthy new results in the field of high strain fatigue. That the magnitude of cyclic strain hardening exponent is related to the extent of deviation from Masing behaviour is another new result of importance to low cycle fatigue.

Notable aspects of the work of Rao and coworkers on power-law creep and creep fracture pertain to elucidation of the effects of polycrystal grain size on high temperature strength, creep rate, creep ductility and creep rupture life. The role of dislocation substructure induced by thermomechanical treatment, and the complex effects that arise due to the interplay of the same with creep-induced development of dislocation substructures has been analysed in great detail in an Al-Mn alloy specially suited to this work. The work on the role of grain boundary migration led to the discovery of the occurrence, during creep, of the so-called diamond grain morphology, a surprising microstructural development. In another investigation, the presence of an anodic surface oxide was shown to strongly inhibit the creep of even polycrystalline metals. By the use of the scanning electron microscope, details hitherto unnoticed in the transgranular creep fracture of Al were unravelled, while showing that although intergranular failure was conspicuously absent during creep, intergranular cracking occurred during fatigue of Al at high temperatures. Rao and coworkers have also carried out studies on the low stress viscous creep of cobalt, titanium, zirconium and zircaloy and have obtained interesting results. In the course of this work, experimental evidence has been obtained, for the first time, for the occurrence of Harper Dorn creep at temperatures as low as 0.5 T_m, where T_m is the absolute melting temperature; this was until recently considered to occur only at temperatures close to the melting point. For the first time, experimental creep mechanism maps covering viscous as well as power-law creep mechanisms have been constructed for alpha-titanium, alpha-zirconium and beta-cobalt.

The relationship of microstructure and internal structural features that can be revealed only with high resolution techniques, with mechanical properties, constitutes one of the foundations of the new science of engineering materials. However, the only mechanical property which has been researched in this light so far, to such an extent that not only control of such a property in the existing alloys can be exercised but also design of new engineering alloys can be attempted, is the yield strength. There are a number of other properties of great significance to mechanical performance where similar understanding is yet to emerge. This is the major concern of Rao's current work. One instance of notable work in this context relates to the understanding of the role of stacking fault energy in the mechanical damage caused by solid particle impingement utilizing a series of copper-base solid solutions. In another instance, the subtle influence of microstructure on fracture toughness has been elucidated in terms of grain boundary chemistry and transformation products resulting from heat treatments of an ultrahigh strength maraging steel. The microstructural effects on fracture processes in aircraft high temperature titanium alloys have been studied and fracture mechanism maps have been constructed for titanium and a series of its alloys. A major effort has been presently undertaken to understand the fundamental role of solute additions in determining the resistance to failure in metallic systems.

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G S Ramaswamy

(1) Overview of Research Achievements

My major contributions by way of research, development and innovation during the past 35 years have been in the area of long span roofs and floors which provide large unobstructed spaces uncluttered by columns for auditoria, conference halls, indoor sports' stadia, cathedrals, industrial sheds and institutional buildings. The research carried out has led to the development of new or improved materials, new structural forms, simplified methods of structural analysis and appreciable savings in critical materials, such as cement and steel, which are often in short supply. The underlying objective of all of my research activities has been the development of structural forms and techniques that result in the use of a minimum of materials to maximum structural advantage. These considerations ions led me to concentrate my research efforts on two major areas: (i) concrete thin shells, and (ii) reinforced and prestressed concrete, which offer considerable scope for developing cost-effective structural schemes for long spans. The research carried out in these areas has led to the publication of two internationally known and widely used text and reference books: *Design and Construction of Concrete Shell Roofs* (McGraw-Hill, 1968; Krieger, 1984), and *Modern Prestressed Concrete Design* (Pitman, 1978). I have also authored around 100 technical papers and taken out six patents in association with my coworkers. Owing to fortuitous circumstances, I have had the opportunity of working as a Professor, Research Director, UN Adviser and Structural Engineering Consultant during different phases of my career. This varied experience made it possible for me to bridge the yawning gulf that often separates research from practice by incorporating the findings of my research in some of the pace-setting structures that I designed as a consultant. Another major achievement was the establishment of the Structural Engineering Research Centre, a national laboratory of CSIR of which I was the founder director.

(2) Contributions to Thin Shells

Although I have made several original contributions to the theory of cylindrical shells[1,2], conoids[3] and prestressed hyperboloids[4], and shared the Gammon prize for developing design principles for the first-ever folded plates built to be continuous over three spans[5], my most significant contribution is the development of a new form of shell which has come to be known as the funicular shell. The motivation for developing this new form of

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shell was rooted in necessity. In the late 1950s, the country was faced with an unprecedented shortage of cement and steel. Just at that time, the Ministry of Defence had plans to build 1400 houses for army personnel at Ambala. I was asked to come up with a roofing element that can be made *sans* cement *sans* steel. I thought of some form of shell roof. But all shell forms, then known, have tension regions and they cannot be cast without steel reinforcement. Lime-surkhi mortar that I proposed to use to save cement is fairly strong in compression, but it has hardly any tensile strength. Obviously, I had to find a shell form which will develop only pure compression when submitted to the action of loads. I was led to the conclusion that to achieve this, the normal sequence followed in the design of shells must be reversed. Instead of assuming an arbitrary geometry and topology to start with, one must assume a desired state of stress, say uniform compression, and proceed to find the appropriate shape. This led to the funicular form. The first papers on this new form of shell were published in 1958[6–8]. A simple casting technique using a hessian fabric sagging under the weight of wet surkhi mortar to let the shell 'cast itself' to the appropriate shape was also devised and patented[9] to permit the mass manufacture of such shells even in the remote villages of India using unskilled labour. The shape of the funicular shell is governed by Poisson's differential equation and the casting technique just described amounts to letting gravity solve the differential equation. The best examples of funicular brick shells built in India are those designed by me and my colleagues for the National Institute of Design at Ahmedabad and the Structural Engineering Research Centre at Madras. These were cast on accurately cut forms conforming to the funicular shape. Other notable examples are the shell roof over the municipal auditorium at Kanpur and the Catholic Cathedral at Lucknow. The development of the funicular shell attracted wide international notice and the papers published on this subject were translated into Russian and German. Many honours and awards followed. I received the Inventions Promotion Board Award for this contribution. In 1961, I was invited to deliver a special lecture on funicular shells at the International Conference at Delft[10]. This was soon followed by an invitation under the auspices of the National Academy of Sciences to act as a chairman for the World Conference on Shells at San Francisco and deliver lectures at some US campuses. Soon an opportunity arose for using shells for an unprecedented application at Madras Port for the heavy duty floor of a loading platform for carrying heavy industrial loading. The report on this project[11] attracted the attention of the Naval Civil Engineering Laboratory at Port Hueneme, California. With my published work as a point of departure, the Naval Research Laboratory carried out exhaustive investigations for three years and recommended funicular shells for naval applications.

(3) Contributions to Reinforced and Prestressed Concrete

My research efforts in the area of prestressed concrete have been aimed at gaining a better understanding of the twilight zone between fully prestressed and reinforced concrete, so that an integrated approach to the design of reinforced concrete and prestressed concrete becomes possible by regarding them as the two ends of the spectrum of structural concrete. This approach has been presented in my book[12] and a paper read at the FIP Congress held in New York[13].

In a joint paper[14] with my coworkers, I conclusively demonstrated that a saving of 33% in the steel used as concerete reinforcement aggregating to a total of 0.45 million tonnes of steel per annum can be effected if reinforced concrete structures are designed on the basis of ultimate strength and high yield strength deformed bars replace mild steel as reinforcement. This paper had a far-reaching impact on the building industry. It ushered in the changeover from elastic to ultimate strength design; it also generated a demand for high strength deformed bars. To meet this demand, one of my colleagues and I developed and patented a high strength deformed bar. Manufactured and marketed under the trade name of TISCON by TISCO, it replaced imported TORSTEEL technology. For this research and development work, I received the Indian Merchant Chamber Diamond Jubilee Award for outstanding achievement; the Structural Engineering Research Centre which I headed at that time was awarded an import substitution shield.

(4) Future Directions of Research

During the next five years, I expect to be involved in the following research activities:

(i) *Compiling a monograph on funicular shells* : The aim of this project is to document my contributions and the published work of others, which being widely scattered in numerous publications, are not easily accessible. I also intend to initiate some additional studies, the findings of which will also find a place in the monograph. These additional research investigations will generate a lot of thesis material. Hence, they are best pursued in an academic environment in collaboration with young research colleagues.

(ii) *Development criteria for the design of tall structures submitted to the action of wind loads* : Because of the current trend towards superthermal power stations, a large number of very tall chimneys and cooling towers ranging in height from 100 to 250 m are either under construction or are on the drawing boards. Such structures can be designed economically only if the wind velocities, and hence the wind pressures for which they are to be designed, are prescribed rationally. A stochastic approach based on the analysis of data available on wind velocities must replace the current deterministic codes and computer-based methods of structural analysis need to be developed. This programme can be best pursued in an institution in collaboration with young research colleagues.

(iii) *Development of inflatable forms for casting concrete shells* : The cost of formwork constitutes a major proportion of the total cost of a concrete shell roof. An appreciable reduction in cost can be realized if inflatable forms can be developed and used. The scope of the research planned includes the formulation of design principles and development of practical details.

(iv) *Development of designs and the planning of a pilot project involving the building of a solar chimney* : Combining the principles of a greenhouse, the windmill and a chimney, the solar chimney offers a cost-effective means of tapping solar energy and converting it into electrical energy in a country such as India. The main component involved being a tall chimney, the problems involved in developing an economically viable unit are in the realm of structural engineering. This project is best pursued in an institutional environment, where inter-disciplinary inputs and interaction are possible.

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S Ranganathan

The central paradigm in the design of alloys is the strong connection that exists between microstructure and properties[1]. The exploitation of this principle depends upon our ability to analyse the microstructures by a variety of metallographic techniques and to synthesize the desired microstructures by various processing routes[2]. Early work revolved around the field-ion microscope with atomic resolution capabilities. Extensive use of geometric analysis and computer simulation was made to solve the problem of contrast from perfect crystals as well as dislocations, stacking faults and domain boundaries. A significant contribution has been the development of the coincidence-site lattice theory of atomic configuration at grain boundaries in metals[3]. More recent work has centred around the use of the transmission electron microscope to follow the evolution of microstructure during phase transformations, such as ordering and spinodal decomposition. Current emphasis is on metallic glasses and metastable alloys. Computer modelling and high resolution electron microscopic observation of the structure of interfaces and the progress of transformations are being initiated now to gather further insights into form and growth in metallic systems.

Phase Transformations

Ordering and clustering are opposing tendencies in alloys. Nevertheless, they can both occur by a continuous mode. During an investigation of ordering in Ni-Mo and Ni-W alloys, the nature of short range order and the occurrence of metastable phases received attention[4]. The complicated sequence of transformations in Ni_3Mo has been followed to establish the time-temperature-transformation curve. The strengthening arising from ordering in these alloys has been conclusively traced to domain size.

The ageing temperature played an important role in the mode of transformation in Ni-20% W alloy. At relatively high temperatures (940°C), a heterogeneous mode prevailed. Perpendicular twins formed and new domains were nucleated near grain boundaries. At lower temperatures (830°C), homogeneous nucleation occurred, leading to a mosaic structure. Thus, it is possible to vary the microstructure in the ordered alloy by making suitable changes in the heat treatment schedule. The influence of chromium addition on the mode of transformation in this alloy is presently under study.

Spinodal decomposition in Co-Ti alloy has been studied[5]. Though matrix and precipitate structures are the same as those encountered in the nickel-base super-alloys, the transformation occurs by

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a different route. The kinetics of coarsening of the modulation, the development of particles, the loss of coherency and the generation of misfit dislocations were monitored to yield a wealth of information which enabled the correlation of microstructure with the strength values attained.

Discontinuous precipitation and eutectoid decomposition are very different in mechanisms and kinetics from ordering and spinodal decomposition. The kinetics of discontinuous precipitation that sets in in Co-Ti alloys at the end of spinodal transformation has been studied[6]. While eutectoid transformation is generally a slow process, it cannot be suppressed even by fast quenching in some titanium and zirconium alloys. Such active eutectoid systems have been taken up for study in collaboration with the Bhabha Atomic Research Centre, Bombay.

The role of grain boundaries and interfaces in transformation is an area of current interest. The possibility that the transformation from one close-packed structure to another in cobalt alloys occurs by dissociation of grain boundary dislocations has been examined. It was demonstrated that this could not serve as a general mechanism[7]. This area of research will be further extended with computer modelling and high resolution electron microscopy.

Metallic Glasses

Metallic glasses possess attractive mechanical, magnetic and chemical properties. As part of a nationally coordinated project aimed at producing glasses suitable for transformer applications, the thermal and chemical stability of amorphous alloys has been investigated.

The crystallization behaviour of a wide variety of glasses, e.g. Vitrovac 0040 ($Fe_{49}Ni_{40}B_{20}$), Metglas 2826 ($Fe_{40}Ni_{40}P_{14}B_6$) and Metglas 2826 MB ($Fe_{40}Ni_{38}Mo_4B_{18}$), has been followed using differential scanning calorimetry and transmission electron microscopy. Nucleation of crystals and their subsequent growth were studied from the kinetic and mechanistic points of view. A comparison among the three modes of crystallization, namely, primary, eutectoid and polymorphic crystallization, was formulated. A new relationship among activation energies for different processes was postulated. A new and as yet unexplained observtion is the increase in interlamellar spacing with decreasing temperature[8,9].

The electrochemical corrosion of Vitrovoc 0040 as a function of chloride and sulphate concentrations has been investigated through potentiodynamic studies in the glassy and crystalline states. The anodic polarization curves of both amorphous and devitrified alloys showed selective dissolution of iron near the corrosion potential. Using ESCA, it was shown that the sequence of dissolution of the alloy is B, Fe and Ni in +3, +3 and +2 state, respectively[10].

Metstable Alloys

The American Society for Metals has embarked on an ambitious programme on the evaluation of phase diagrams. As part of this effort, the evaluation of cobalt ternary diagrams is under way with Ranganathan as Category Editor.

While the phase diagrams offer useful guidelines for the development of alloys, these imply certain restrictions. These limitations can be evaded to prepare metastable alloys far away from equilibrium by using a variety of techniques. Rapid solidification of a number of aluminium alloys has been accomplished and the nature of the metastable phases produced determined. This is now being extended to titanium alloys in collaboration with the National Aeronautical Laboratory, Bangalore.

A new area of research involving laser processing of alloys has been established. A high energy laser beam melts a thin surface layer of an alloy which solidifies in contact with its own substrate. Fine microstructures and metastable phases have been produced in metals (A1, Sb, Zn), eutectics (A1-Si, Zn-Sn) and coatings (Sb-A1 and A1-Sn). An extensive study of a number of eutectic and monotectic aluminium alloys is in progress.

Quasicrystals

Aperiodic tilings were discovered by R Penrose as an exercise in mathematical recreations. Their possible existence was the dream of physicists such as A L McKay. They became a metallurgical reality, thanks to the discovery of quasicrystals in rapidly solidified Al-Mn alloys by D Shechtman and coworkers in November 1984. The most fascinating aspect of these materials is the generation of sharp electron diffraction patterns.

We have studied the variety of electron diffraction patterns produced by quasicrystals and compared them with computed patterns[11,12]. We have also shown that a remarkable relationship exists between quasicrystals and T-phases, interpretable in terms of the dimensionality of incommensurate modulations[13]. Further work is aimed at exploring this relationship so as to understand the series of structures that span the range between quasicrystals and apparently complex crystalline phases.

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P V S Rao

India's First Computer

Rao started his professional career with the design and development of TIFRAC, India's first computer at the Tata Institute of Fundamental Research.

This activity was started from scratch, by him and others who, being first generation computer scientists, did not have any previous training, experience or exposure to work in this area. He designed and built the arithmetic unit and the cathode ray display system for TIFRAC. These incorporated several innovative features (carry bypass logic for fast addition, design of high speed glitch-free shift counters, etc.).

In his PhD thesis project, he introduced, in the 1950's, a new scheme for line-segment display of alphanumeric characters; this improved legibility and clarity and reduced memory requirements. This was the first time that line segments were used for character display. The idea subsequently became very popular for high quality CRT displays, graphic plotters, non-impact printers, etc.

Second Computer

After returning from the University of Illinois (where he worked on the design of the high speed ILLIAC II computer, Rao was involved with hardware developmental activity at the Tata Institute of Fundamental Research. His responsibilities during this period included establishing a digital systems laboratory involving 15-20 scientists and engineers to undertake various system design and implementation tasks. OLDAP, an on-line data processor, was designed and built by this group.

The machine, the first of its kind in India, was built using locally made entertainment grade components. Building reliability and speed into a large system using slow, non-switching junction transistors and point contact diodes meant for the entertainment industry, was a challenging task which was successfully accomplished by him and his team. The system (i) demonstrated the feasibility of designing large digital systems using mainly Indian components, (ii) highlighted the utility of online computers for real applications in India, and (iii) gave rise to a number of innovative ideas in the area of digital circuits and system design, e.g. a fast circuit switching logic module which utilizes slow transistors and junction diodes not intended for such applications; a simple peak detector readout circuit for magnetic disk units; and a highly regulated very low voltage power supply with fail-safe short circuit protection and reliable power supply interlock controls.

The impact of this work on the national scene has thus been quite significant on all three counts.

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The design of this computer was futuristic. Many of the system design features incorporated here (such as flexible register assignment, a variety of addressing modes, two-address instruction scheme, etc.) became available only several years later in commercial machines offered by leading manufacturers.

Large Systems for Major National Needs

As a consequence of the competence so established, the group under Rao's leadership was assigned the total responsibility for two national projects for realizing (a) a command and control system, and (b) a switching system for voice, teleprinter, facsimile and digital data. These, the largest of their kind, were launched by the Government of India as inter-institutional projects, since the requisite know-how did not exist in any one institution.

The task forces formed to realize these systems consisted of about 80 engineers, scientists and senior officers from the Tata Institute of Fundamental Research, government and private sector laboratories and industry, as well as the Indian Army and Air Force. Additional work was done by groups at these institutions which were given responsibilities for specific subsystems, also under Rao's supervision.

The work involved system design, system engineering, hardware design, development of systems and applications software, finalization of production prototypes, ruggedization, environmental and other testing and establishing a production line for the products.

The development projects and the systems developd were the largest of their kind ever to be attempted in India in the area of electronics.

The systems designed and developed by this group successfully underwent the full range of defence specification tests as well as hardware and software performance tests under operational conditions of temperature, humidity, shock vibration, transportation, etc. and are currently under operational use.

Speech and Signal Processing

Rao initiated activity in the area of speech synthesis and recognition by computer in India at the Tata Institute of Fundamental Research. Several important and original contributions were made by him and his coworkers in the area of speech research.

He proposed and implemented a novel scheme for computer synthesis of speech which is flexible, simple and elegant: grouping phonemes into equivalence classes and sub-classes (on the basis of similarity of context influence on neighbours) and defining phoneme concatenation rules for these classes and sub-classes instead of for individual phonemes. His conjecture that such a classification would be closely parallel to the one based on articulatory similarities turned out to be correct and represented a significant insight.

His scheme for speech recognition utilizes information contained in formant transitions for improved recognition scores. Also, it is synthesis-based: it employs transition segments synthesized on the spot rather than prestored templates for comparison with the test sample. In a clever way, this prevents variations in the steady segment properties from interfering with recognition of the transition segments, and yields a significant improvement in the recognition scores. In this scheme, recognition based on steady state segments is followed by that using transition segments. As variations in vowel parameters will affect CV/VC transitions, use of prestored templates for recognition is undesirable; transition templates are, therefore, synthesized on the spot using vowel parameter values extracted from the sample under recognition. This makes recognition of CV/VC transitions insensitive to vowel formant variability.

Recognition scores are 52% (using steady state segments only) and 64% (using transitions also), illustrating the validity of this approach. Rao was the originator of this scheme.

His work shed light on an important aspect of speech perception in the human brain. Formant transitions which are important cues for perception of stop consonants are, to a certain extent, also influenced by contextual effects due to non-immediate neighbours. This work has established that these effects are not important for human speech perception.

The human listener looks at the speech signal only two phonemes at a time and is concerned only with context effects of adjacent phonemes on each other. This result is of relevance for machine synthesis and recognition of speech.

A cross-linguistic study performed in this area threw light on another interesting aspect of the human speech perception mechanism. He and his collaborators have also been responsible for a number of other original ideas in the areas of speech signal processing, pitch extraction and so on.

Policy Planning and Implementation for Technology Development

In addition to work in the areas of computer systems and speech research, Rao was concerned with and played an active part in the evolution of policy and planning for technology development in electronics in general and the area of computers in particular.

As a member of the Technology Development Council and Chairman of the Working Group on Computer Systems and Applications, Department of Electronics, Government of India, it was his responsibility to identify and promote well chosen research activity to be financed by government in selected thrust areas, identify suitable projects for funding and monitor their progress.

As Chairman of the Panel on Mini Computers of the Government of India, he was responsible for a comprehensive analysis of the need for mini-computers, evolving a policy approach for establishing and licensing of manufacturing and suggesting an overall framework for the growth of research and development in this field.

As Chairman of various official committees in the area of education in computer science and technology, Rao played a prominent part in shaping the educational policy of the country in this important field.

Rao is a Fellow and past President of the Computer Society of India. He is, in addition, a Fellow of the Indian National Science Academy, Indian Academy of Sciences, Acoustic Society of India and Institution of Electrical and Telecommunication Engineers, India. He was elected Distinguished Visitor for Region 10 (South

East Asia and Japan) of the Computer Society Chapter of the Institution of Electrical and Electronic Engineers in 1981-82. Rao won the Vikram Sarabhai Research Award for 1976.

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G S Sanyal

Sanyal has been engaged mainly in research in the field of electro-magnetics and its application to microwave and antenna engineering over the past few decades.

His initial research work dealt with the estimation of ferromagnetic permeability in the microwave frequency band. He devised an experimental set-up for its measurement. Later, he developed the conformal transformation for the determination of amplification factor of triode having elliptic cross-section. This was followed by extensive investigations into aperture type antennas. While studying the radiation pattern from the open end of X-band rectangular waveguide, he analysed the effect of cutting the waveguide with different inclinations towards its axis. A discussion on this work, which has been widely referred to, was included in the Book "*Antenna Engineering*" by Jasik.

In the course of further investigations, he made useful contributions to the field of slot antennas by evaluating their self and mutual impedances in the wall of rectangular waveguide. This yielded dependence of radiation pattern and impedance characteristics of slots on the field distribution in the aperture plane of slots, indicating excellent correlation between theoretical and experimental results.

He also took up investigations regarding the sectoral horn antenna with curved aperture. The radiation pattern for both concave and convex cuts on the face of E plane and H plane sectoral horns was formulated and almost simultaneously, studies on periodic structures were conducted. In continuation of these, he found ω-β relation for sinusoidally modulated rectangular waveguide and assessed the dispersion characteristic and the condition for matching. He further made a formulation for periodic structures consisting of X-band rectangular waveguide, periodically loaded with thin posts. These studies showed excellent correlation between theoretical and experimental aspects.

At the Indian Institute of Technology (IIT), Kharagpur, he established a new centre of research activities named Radar and Communication Centre (RCC). He was able to create and guide there a highly motivated research group on antenna and microwave engineering. This group undertook many project works in the field of radar and communication funded by the Ministry of Defence, Department of Electronics, ARDB and other organizations and made notable contributions.

As initiator of research work in the field of phased array antenna, he explored many new aspects of different types of phased arrays and their feeds. Many

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Director, Indian Institute of Technology, Kharagpur-721302; *Residence* : Director's Banglow. IIT Campus, Kharagpur-721302 prototype phased arrays and phased array components were developed, which are available in the Microwave and Antenna Engineering Laboratory of IIT, Kharagpur. Investigations into different aspects of phased arrays were performed by researchers attached to the RCC and their results were published in reputed journals like *IEEE Transactions*. Along with the study of some new aspects of non-uniformly spaced array, impedance formulation was prepared using plane wave spectrum approach. This work found mention in a large number of publications, including journals like *IEEE Transactions*.

Sanyal has also carried out research on improvement in front-to-back lobe ratio of parabolic antenna by using shrouds and has succeeded in achieving positive results in this important aspect of antennas.

In 1979, he established the facility of research in the fields of fibre optics and fibre optics communication. He has organized several short-term courses and summer and winter schools on this topic and till now he is associated with research in this area. In addition, he has been participating in the development of antenna systems for navigational aids and radar. His research activities have been highly appreciated and recognized by various agencies in the form of many awards, prizes and honours.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

M M Sharma

Gas-Liquid Reactions

New theories for complicated reaction systems have been developed and these have resolved many paradoxes. New techniques have been developed which allow kinetics of extremely fast reactions to be studied. Linkages between theory and practice have been established.

New systems have been suggested which would conform to a particular regime of mass transfer with reaction and thereby enable the determination of transport coefficients as well as interfacial areas by chemical methods.

Novel strategies have been suggested to increase the rates of fast gas-liquid reactions; these include the use of second liquid phase, emulsified with the original liquid phase, which shows much higher solubility for the solute. Areas requiring attention are: reactions in non-Newtonian fluids; simultaneous absorption-desorption with reaction, etc.

Liquid-Liquid Reactions

The chemical method of measurement of interfacial areas in liquid-liquid systems was introduced. Many novel aspects of enhancement of fast and slow liquid-liquid reactions have been proposed and verified. In particular, the role of phase transfer catalysis, micellar catalysis, hydrotropy and small carbon particles has been brought out in an innovative way.

A novel room temperature process for the preparation of triaryl phosphate has been developed which exploits phase transfer catalysis in an imaginative way. New areas of work include study of reactions involving three liquid phases; simulation of emulsion polymerisation reactions; and reactions in microemulsion media.

Three-Phase Reactions

The effect of the presence of micron sized particles, smaller than the diffusion film thickness, in slurry reactors, has been clearly established. A new theory, which accounts for the dramatic enhancement in the specific rates of mass transfer, has been developed. Earlier, a new theory for situations where sparingly soluble fine particles are encountered in instantaneous reactions was developed; it has important applications in flue gas desulphurization. New areas include simulation of slurry polymerization reactors; reactions involving two liquid phases; and use of colloidal particles as catalyst.

Engineering Analysis and Design of Gas-Liquid and Liquid-Liquid Contactors

Systematic studies on the performance characteristics of conventional as well as

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unconventional types of contactors have been made. New scale-up and design concepts have been suggested for a variety of contactors, notably bubble columns and mechanically agitated contactors; new strategies for operating such reactors have been suggested. Measurements of local values of heat transfer coefficients in bubble columns have been made through an ingenious study of mass transfer coefficients.

New Separation Methods

Separations of several close boiling acidic/basic mixtures by dissociation extraction have been accomplished. New regenerative methods have been developed. A new technique of dissociation extraction-crystallization has been developed. Hydrotropic effects have been utilized to carry out separations of close boiling substances.

Recovery of Chemicals from Liquid Waste Streams

Novel methods have been developed to recover toxic chemicals from waste streams, including phenolic materials in alkaline systems and nitrobenzene sulphonic acid in aqueous solutions containing sulphuric acid.

Contributions as a Consultant

Many ideas have led to substantial improvements in the existing plants, particularly sodium bicarbonate and soda ash. New strategies in recovering valuable chemicals from waste streams have been utilized; these include recovery of resorcinol from a waste dirty stream; recovery of fumaric acid from waste gases of phthalic anhydride plants, etc. Utilization of several byproduct streams to value-added products has been done.

Solvent extraction has been used in a novel way to treat waste streams from a group of nitroaromatics plants.

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D V Singh

Singh has done extensive work in the area of hydrodynamic and hydrostatic fluid film bearings and seals. His work includes citron and multilobed journal bearings used for large size high speed machines and for radial support of vertical shafts because of their superior stability characteristics, rolling pad hydrodynamic bearing which is a quantum improvement on the conventional tilting pad configuration and is used in precision machine tools for very high speed applications, hydrostatic journal bearings with optimum compensation, hydrodynamic seals, compressible lubricants, non-Newtonian fluids, micropolar fluids, and magnetohydrodynamic lubrication. His in-depth studies cover static and dynamic analysis, design and optimization, and critical interpretations, particularly of the stability characteristics. His work, which has been published in various national and international journals, is widely referred to and has been used in industrial applications. He has organized short-term courses in this field and has been invited by various organizations to deliver lectures.

Singh has done significant work in the area of dynamics of single track vehicles. In India, his is perhaps the only group working on the handling and stability of single track vehicles. He may be credited with the creation of a tyre testing facility at Roorkee, the only machine of its kind in the country to measure the steady state and transient tyre-pavement interaction forces and moments for small sized pneumatic tyres. His work on single track vehicle dynamics includes measurements of actual vehicle parameters, tyre characteristics and wind drag. His mathematical models based on the measured parameters have been authenticated by road tests. The optimum values of the steering configuration recommended by him have been adopted by a leading Indian industry.

His work on the mathematical modelling of the pneumatic tyres to predict tyre response to steering inputs is important. His models can quite realistically predict the steady and transient tyre forces and moments and are invaluable for realistic modelling of vehicles.

He has also done static and dynamic analysis of complex mechanical structures and continuums for leading Indian industries; these include chassis frames of double decker buses, frames of motor scooters, bed plates for assembly of rotor laminations and dynamic test of turbogenerators.

In addition, he has done work on weld pool solidification, effect of welding parameters on metal transfer, spatter, heat affected zones, and changes in

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crystallographic structures correlating the mechanical properties. His work also includes analytical prediction and experimental measurement of residual stresses in and around spot welds.

The behaviour of load supporting thin lubricant film is a widely studied subject. One of the missing links in these studies is the effect of fluid particle inertia, which is important in applications involving very high surface speeds. A formulation to include the particle inertia along with the pertinent nonlinearities and a viable solution of the problem are not yet available. Such a solution will yield realistic results for the design of bearings for critical applications and selection of parameters to ensure better dynamic characteristics, reliability and longer life.

Establishing an analytical model for single track vehicles is considered as a more rigorous task than actually solving the model. A general model to include unsteady state turning, with large lean and steering angle, and taking into account the frame flexibilities and realistic tyre response, is not yet available. One distinctive approach, which is feasible with the advent of supercomputers, is to generate equations of motion in symbolic form in the computer itself. This approach has been used with some success for the so-called straight ahead and upright motion, but is yet to be established for the general motion.

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C V Sundaram

Flowsheet development for the extraction and fabrication of rare metals and their alloys, and the development of special materials for specific functional applications, have been major components of the Metallurgy Programmes in the Department of Atomic Energy. Basic research in this field has involved the application of the principles of metallurgical thermochemistry to the extraction and purification of rare metal halides, metallothermic reduction of halides, carbothermic and aluminothermic reduction of oxides, pyro-vacuum metallurgy and studies on phase equilibria. Based on these extensive researches, pilot plants have been designed and operated successfully for the production of nuclear grade zirconium sponge metal (starting from Indian zircon), titanium sponge metal (starting from rutile) and beryllium metal and copper-beryllium alloy (starting from beryl). In all this work, special emphasis has been placed simultaneously on the development of indigenous capability for fabricating sophisticated equipment and machinery.

(1) Zirconium and Hafnium

In water-cooled nuclear power reactors, an alloy of zirconium is extensively used as a cladding material for the uranium oxide ceramic fuel and also for the fabrication of structural components, such as pressure tubes and calandria tubes. The zirconium alloy offers advantages of low neutron absorption cross-section, good strength and ductility at the operating temperatures and excellent corrosion resistance in high temperature water.

The natural source material for zirconium is the mineral zircon which is a zirconium silicate invariably associated with a small percentage of hafnium. Zirconium and hafnium are extremely close in their chemical properties; on the other hand, hafnium is a strong neutron absorber and removal of hafnium is a very important step in the nuclear metallurgy of zirconium.

In the first phase of the Department of Atomic Energy's research programme on zirconium (at the Indian Institute of Science, Bangalore), two entirely new processes were investigated: (i) selective vapour phase dechlorination of zirconium tetrachloride to form low-hafnium zirconium oxide, and (ii) selective reduction of zirconium tetrachloride with aluminium to form nonvolatile zirconium tri- and dichlorides. By adopting the second route, nuclear grade purity could be achieved in a two-step operation.

For the preparation of ductile nuclear grade zirconium sponge in kilogram quantities, starting from zircon, an integrated flowsheet was established involving (i) sintering of zircon with potassium silicofluoride to form potassium

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zirconium and hafnium fluoride; (ii) fractional crystallization/purification of potassium zirconium fluoride; (iii) conversion of potassium zirconium fluoride to zirconium hydroxide and calcined zirconium oxide; (iv) chlorination of the oxide to zirconium tetrachloride; (v) magnesium reduction of zirconium tetrachloride in argon atmosphere to form zirconium sponge; (vi) pyro-vacuum treatment of zirconium sponge to remove magnesium and magnesium chloride; and (vii) crushing and grading of the sponge metal.

The above work provided the basis for the establishment of a full-scale production plant for zirconium sponge, of 80 tonnes per year capacity, which has been in operation at the Nuclear Fuel Complex, Hyderabad, since 1971, meeting the requirements of zirconium metal for the nuclear power programme. In the context of expansion of production capacity to meet the growing requirements, alternative flowsheets and equipment designs for larger batch reductions are under study.

(2) **Titanium**

The extractive metallurgy of titanium bears close similarity to that of zirconium metal. There is a growing demand for titanium metal and its alloys in the country for applications in the aerospace industry and the chemical process industries.

After initial studies at the Bhabha Atomic Research Centre, Trombay, a pilot plant was established as part of the Nuclear Fuel Complex, Hyderabad, for the production of titanium sponge metal (in 75 kg batches). The flowsheet involved: (i) fluidized bed chlorination of rutile to produce crude titanium tetrachloride; (ii) purification of the chloride by H_2S treatment and fractional distillation; (iii) magnesium and sodium reduction of the purified chloride to produce titanium sponge/granules; and (iv) treatment of the sponge by pyrovacuum/acid leach techniques, crushing and grading of the sponge. High quality titanium sponge metal could be produced both by Mg reduction and sodium reduction.

Initial studies have also been carried out on the fused salt electrolysis of titanium tetrachloride employing a special cathode.

The technology of titanium sponge metal production has now been transferred to the Defence Metallurgical Research Laboratory, Hyderabad, where the construction of a plant to produce the metal in 2 tonne batches has been completed.

(3) Electro-refining of Zirconium and Titanium Scrap

The conversion of zirconium and titanium metals to finished industrial components is associated with the generation of a considerable quantity of scrap, not all of which can be directly remelted for reuse. Electrorefining of the scrap metals using a fused salt bath offers an elegant route for reclamation. With special design cells, optimum parameters with respect to bath composition, temperature and current density have been established to obtain the pure metal in kilogram quantities.

(4) Niobium and Tantalum

Niobium and tantalum co-occur in nature in the form of columbite and tantalite minerals. Niobium finds important applications as an alloying addition to zirconium and also as a base for superconducting niobium-titanium alloys.

Tantalum, by virtue of its high melting point, excellent corrosion resistance and special electronic properties, finds application in high temperature alloys, electrolytic capacitors and in the chemical process industries.

In the extractive metallurgy of both niobium and tantalum, high vacuum pyrotreatment and electron beam melting are important final refining steps, as the last traces of oxygen can be removed effectively in the form of volatile metal suboxides by such treatment.

Detailed thermodynamic analyses have been carried out on the reduction of the oxides of niobium, tantalum, zirconium and hafnium by carbon and aluminium. A new route has been established for the preparation of zirconium-niobium alloy and hafnium-tantalum alloy by carbide-oxide reactions.

(5) Beryllium and Copper-Beryllium Alloy

Beryllium metal finds extensive applications in aerospace and nuclear engineering by virtue of its unique physical and nuclear properties. There is also a large demand for copper-beryllium alloy in the industry on account of its good fatigue strength and electrical conductivity.

The natural source material for beryllium is the mineral beryl, in which Indian resources are sufficiently abundant. Based on comprehensive laboratory studies, a flowsheet has been established for the preparation of vacuum hot pressed beryllium and copper-beryllium ingot starting from Indian beryl, and involving (i) sintering of beryl with sodium silicofluoride; (ii) extraction of sodium beryllium fluoride; (iii) preparation of beryllium hydroxide and pure crystals of ammonium beryllium fluoride; (iv) decomposition of ammonium beryllium fluoride to beryllium fluoride; (v) magnesium reduction of the fluoride to produce beryllium pebbles and copper beryllium master alloy; (vi) vacuum melting of beryllium, and (vii) lathe chipping, milling and vacuum pressing of beryllium powder to produce beryllium blocks.

A pilot plant is presently in operation for meeting the requirements of beryllium in atomic energy, space and electronics programmes.

(6) Special Materials Development for Fast Breeder Reactors

The development of fast breeder reactors forms the second phase in the Indian Nuclear Power Programme. The fast breeder reactors will use plutonium in sintered ceramic form as the fuel, liquid sodium metal as the coolant and special stainless steels for many of the major reactor components. At the Indira Gandhi Centre for Atomic Research at Kalpakkam, basic and applied research programmes have been undertaken in the areas of Materials Science and Materials Development, Chemistry, Fuel Reprocessing, Reactor Engineering and Reactor Safety. Structure-property correlation and performance evaluation of stainless steels at high temperature and in liquid sodium environment, simulation of radiation damage employing accelerators, chemistry of liquid sodium, physico-chemical measurements in plutonium-bearing fuels, equipment and process development for fast reactor fuel reprocessing, and development of liquid sodium technology are some of the major activities in the R&D programmes. The Fast Breeder Test Reactor (FBTR) that has now been commissioned uses a new fuel composed of 70% plutonium carbide-30% uranium carbide, developed by the Radiometallurgy Division at the Bhabha Atomic Research Centre, Trombay. The reactor will be a test bed for the testing of new fuel compositions and new structural materials in the reactor environment. These programmes will provide the experience and information base for the setting up of a commercial size Prototype Fast Breeder Reactor (PFBR) (500 MWe capacity).

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G R Toshniwal

After doing his MSc from Allahabad University in 1926, Toshniwal did research in the same university under Prof. Megnad Saha, FRS and got his DSc in 1936. While working as a lecturer at the Allahabad Univerity (1927-45), he organized its Radio Research Laboratory right from the beginning. During this period, he published about 20 papers on ionosphere, spectroscopy and X-rays. His outstanding contributions in ionospheric field related to triplet splitting of the radio wave and the missing third reflection observed for the first time and later confirmed by other workers in the field.

For about three years (1945-48), Toshniwal was at the India meteorological Department, as Meteorologist-in-Charge of the Delhi laboratory and workshop. He was later in-charge of the seismological work of the Department. On transfer to the Magnetic Observatory at Kodaikanal, he was responsible for re-starting the Magnetic observatory after about 20 years.

From 1948 onwards, Toshniwal has been associated with the trade and manufacture of scientific instruments. Starting with import of instruments, he is now one of India's leading manufacturers of scientific and industrial instruments for industry, research and teaching. He has been Chairman and Managing Director, Toshniwal Bros Pvt Ltd (1948). He is now Chairman Toshniwal Industries Pvt Ltd. Earlier, he was Chairman, Prestige Counting Instruments (P) Ltd, Bombay; and Toshniwal Sperry Ltd, New Delhi.

Toshniwal has been associated with a number of departments and professional bodies. He served as Director of Rajasthan Small Industries Corp., Jaipur, and Rajasthan Industrial Development & Investment Corp. He has been associated with the Council of Scientific & Industrial Research as Member, Executive Council, Central Electronics Engineering Research Institute, Pilani; and the Central Scientific Instruments Organization, Chandigarh. He has been a member, Development Council for Instruments from 1958 to 1978 and from 1983 till 1985. He was also a member of the various committees of ISI.

He was President, Section of Engineering & Metallurgy, Indian Science Congress Association (1972), Institution of Electronics and Telecommunications Engineers (1972), and Magnetic Society of India (1981-83). He is a Fellow of the Indian National Science Academy and distinguished fellow of the Institution of Electronics and Telecommunications Engineers; and member, Institute of Radio Engineers, New York (1938) and Life Senior Member of the Institute of Electrical and Electronic Engineers, New York (1943).

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H V K Udupa

The main areas of research and development work of Udupa have been Dye intermediates; Textile technology; and Electrochemical science and technology.

(1) Dye Intermediates

Udupa started research work as a research assistant in a CSIR scheme conducted by Dr B B Dey at the Presidency College, Madras, on 'Electrolytic reduction of nitro compounds leading to the manufacture of direct cotton colours'. As part of this programme, he did pilot plant scale work on the chlorination of benzene, phenol, chlorobenzene, nitrobenzene, toluene, nitrochlorobenzene, *p*-dichlorobenzene, etc. Kilogram quantities of these chemicals were made and the isomers separated by such unit operations as fractional distillation, steam distillation, fractional crystallization, etc.

For the conversion of nitrochloro compounds into nitroanisoles and nitrophenetoles, catalysts like manganese dioxide, lead dioxide and cuprous oxide were used[1-3]. Patents were taken on these novel aspects and several papers were published. Electrolytic reduction of nitro compounds in acid and alkaline media was studied and processes were developed for preparing compounds relating to *p*-aminophenol and benzidine series. Around 30-40 dye intermediates were thus made and processes standardized.

Work carried out during this period formed the subject matter of a thesis on 'Preparation of dye intermediates by chemical and electrochemical methods' which got Udupa the Master's degree in science of the University of Madras.

Research on co-deposition of tin and indium was carried out as part of a programme of work for Master of Arts degree in Industrial Chemistry at Columbia University in the City of New York. Later, at Ohio State University, a new technique involving the use of rotating cathode for the reduction of nitro-compounds to *p*-aminophenols[4,5] was developed, which formed the subject matter of the doctorate thesis. Use of rotating cathodes in the reduction of carbonyl compounds also formed a part of the programme of work for the doctorate degree.

(2) Textile Technology

Udupa's two years' work at the Ahmedabad Textile Industry's Research Association included a comparative study of the bleaching of textile fabrics using calcium hypochlorite and sodium hypochlorite. It was found that cellulose degraded to greater extent with sodium hypochlorite than with calcium hypochlorite. The aim of another study was to ascertain the degree of fabric degradation by various physical and

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chemical processes followed in the textile industry. A process developed for giving semi-permanent finish to fabrics using a solution of hydrocellulose in sodium zincate solution was patented[6].

(3) Electrochemical Science and Technology

Major part of the work of Udupa relating to electrochemical science and technology was carried out at the Central Electrochemical Research Institute, Karaikudi. This work covered fields like electroplating, metal powders, electro-inorganic chemicals, electro-organic chemicals, batteries, fuel cells, etc.[7]. New techniques were developed and novel approaches introduced in respect of known technologies.

(i) *Electro-inorganic Chemicals*[7]

A process for the production of cuprous oxide was developed incorporating a cell design for continuous operation[6]. A plant having 1000 A capacity cells was put up and operated.

As part of the programme of modernizing the technology for the production of electro-inorganic chemicals, research relating to the development of suitable insoluble anodes was taken up. This work resulted in the development of graphite substrate lead dioxide anodes for chlorate and perchlorate production. In this way, considerable reduction in graphite consumption in the chlorte industry became possible. For the perchlorate industry, the benefits were considerble saving in energy consumption and substitution of the costly platinum. Four plants of 1 tonne/day potassium chlorate production capacity were put up based on this technology. Two plants were put up for sodium perchlorate production and one for anmonium perchlorate production. During periods of conflict, potassium perchlorate was produced for meeting the defence requirements in 5000A capacity cells. Production of bromate, iodate and periodate using these anodes was also achieved.

Titanium substrate insoluble anodes (TSIA)[8,9] were developed for use in the chloralkali industry, resulting in 10-15% energy saving compared to the existing cells operating in the industry. This development is similar to the DSA developed by De Nora's of Italy. The chloralkali industry has already largely replaced graphite anodes by these new metal anodes and more than 40% of the production today is with these anodes. Experimenting initially with 20 kA mercury cells, anodes were installed in 160 kA cells, operating at 8 kA/m^2 current density. These anodes have been successfully employed in 10 kA and 30 kA diaphragm cells also. The chloralkali industry has benefited immensely from the indigenous development of this technology.

TSIA have been employed successfully in the manufacture of sodium and potassium chlorate also, leading to considerable energy saving.

The development of a lead dioxide-lead bielectrode[10] as a substitute for platinum-lead bielectrode for impressed current cathodic protection is another example of platinum substitution research done for the industry.

(ii) *Electro-organic Chemistry*[7]

(a) The rotating electrode technique[11] was successfully employed in the reduction of salicylic acid to salicylaldehyde, of nitro-benzene to *p*-

aminophenol, and of nitro compounds to the corresponding hydrazo compounds in alkaline medium, and in the oxidation of glucose to calcium gluconate. Entrepreneurs were helped in setting up plants for the production of these chemicals. Improved mass transfer effects enabled the use of high current density in the production of these chemicals in cells of high capacity. Reduction of nitroguanidine, nitrosodimethyl amine and nitro urea was carried out at rotating cathode.

A high rate of reduction of nitro compounds suspended in acid electrolyte has been achieved using the rotating cathode for the preparation of a number of aromatic amines. Work was done on benzoic acid reduction to benzyl alcohol, glucose reduction to sorbitol and maleic acid and fumaric acid reduction to succinic acid. A 200 kg/day capacity plant for the production of succinic acid is being operated in Bombay.

(b) Indirect electrochemical syntheses using electrochemically generated reagents, such as chromic acid, titanous sulphate, bromine, periodate, and trivalent manganese ions have been developed. More than 15 aromatic amines have been made quantitatively from the respective nitro compounds using the titanous-titanic redox system. More than six plants have been put up for the production of calcium gluconate from glucose using the bromide-bromine redox system. Similarly, aldehydes have been made from aromatic hydrocarbons using the manganic-manganous redox system. Dialdehyde starch was made using the periodate-iodate redox system. Saccharin was made using chromic acid.

(c) Reduction of nitriles to primary amines was carried out on carbon cathodes having black nickel, black iron and black cobalt deposits. A 500A cell was put up for this work. In work on the reduction of benzonitrile, benzyl cyanide, mandelonitrile, adiponitrile, dodecyl, cyanide, cyanoacetic acid and 3-cyanopyridine, high yields of the respective primary amines were obtained at satisfactory current efficiencies.

(d) Oxidation of alcohols to aldehydes at electrodeposited oxide electrodes was investigated. Cathodes with deposits of silver oxide, ruthenium oxide, nickel oxide and cobalt oxide on different substrates were also tried.

(e) Use of the technique of interrupted d c electrolysis[12] with cathode rotation was found to give increased yields to the desired product, due to favourable conditions attained for the reaction of the intermediates formed. Substantial increases in the yields of *p*-aminophenol in the reduction of nitrobenzene and of pinacol in the reduction of acetone were achieved.

(iii) *Recovery of Secondary Metals*[11]

Two new techniques were developed for the recovery of secondary metals from non-ferrous metal sources. One of them relates to the recovery of zinc, copper, iron, lead, cadmium, etc. by direct reduction of oxides to give metal powders. Wastes from galvanizing industry, zinc oxide manufacture, hydrosulphite industry and copper utensils industry can be processed to give zinc and copper powders. A plant has been set up based on the technology developed for the production of iron powder from mill scale. Another technique developed involves suspension electrolysis to recover lead, zinc, etc. Plants have been put up for the recovery of zinc from galvanizing industry wastes.

(iv) *Electrodeposition Studies*

Processes have been developed for the electroplating of zinc and lead from alkaline baths using a rotating cathode. Bright nickel plate was obtained from Watt's bath by cathode rotation. Variation in the composition of iron-zinc alloy under cathode rotation conditions was investigated. The influence of various addition agents, such as CTAB, on deposit quality was investigated. Work was also done on brass-plating and cobalt-tungsten alloy plating.

Metal powder[14] deposition on substrates from which it would be easy to collect the powder has been investigated.

(v) *Batteries and Fuel Cells*

Hollow carbon air-depolarized cathodes were developed and investigations carried out to develop secondary zinc-air batteries. Processes were developed for making Planté plates and high performance batteries for low temperature operation by incorporting carbon black in positive plates and organic addition agents in negative plates. Technology was developed for the manufacture of high energy density batteries for electric vehicles. Studies on constant current and constant potential charging of lead-acid batteries showed the latter procedure to be superior.

The possibility of using Indian manganese ore in dry cells was investigated. The technology for making dry cells on a small scale was developed and entrepreneurs were assisted in putting up plants for the same. High capacity sintered-plate nickel-cadmium battery technology was developed and the know-how released to industry. Sealed nickel-cadmium cells technology was developed and entrepreneurs were helped in putting up plants for the manufacture of these cells.

Considerable progress was made in the development of hydrogen-oxygen wet fuel cell and prototype batteries were tested for their life. Investigations were carried out to develop iron-titanium and other alloys for hydrogen storage; the stored hydrogen was used for running a two-stroke engine.

The trend of R & D in the field of electrochemical science and technology is in the direction of achieving energy reduction in processes by adopting newer and novel approaches. An increasingly important role of electrochemistry in various sectors of industry, in corrosion control, pollution control and energy storage is being foreseen. Electrochemistry would also play a vital role in hydrogen economy of the future.

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H L Uppal

(1) Physics of Flow of Water through Pervious Material and Design of Engineering Works on Sand Foundation (1930-37)

A new method for determining the lines of flow through pervious material under works and uplift pressures on the floor was developed. Advantage was taken of the chemical reaction between potassium dichromate and silver nitrate and formation of black silver nitrate lines in the material—sand. Velocities of flow in strategic regions could also be determined.

The old theories of designs of works were exploded and new theories based on these studies were developed. Similarly, the determination of uplift pressures on the floor of the works helped to design economical, safe and sound hydraulic structures. The work was highly appreciated by experts even in outside countries. It was referred to in leading works. This discovery led to the publication of several papers and memoirs[1-10].

(2) Energy Dissipators below Hydraulic Structures and Design of Works (1935-39)

This is another important problem which faced the hydraulic engineers. Below the hydraulic structures on the rivers and the canals, deep and extensive scour holes occur which undermine the safety of the structure and necessitate large expenditures. After an indepth study extending over several years, effective and economical designs of energy dissipators were evolved. These comprised constructing staggered blocks at the toe of the glacy and at the end of the floor. The designs evolved form a part of the work for all structures not only in the country but even outside. The designs replaced the earlier devices, such as Rhebock cill and Inglice's baffle in use. A paper[11] presented at the Punjab Engineering Congress was highly appreciated. Twenty more papers were published later.

(3) Anti-tank Obstacles for Amphibian Tanks (on Rivers and Canals) (1938-41)

Anti-tank obstacles for amphibian tanks were evolved after research in the laboratories as well as in the field during the second world war. These proved highly efficacious and were adopted on rivers in the Kuram and Shinki valleys with great success. Earlier to this development, extensive long steel sheet pipes had to be installed on the river bed at a huge expenditure. The new devices, on the other hand, required only a shallow foundation. The assumptions made earlier anticipating deep scours were found to be incorrect. The new approach was based

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on siltation which occurs in the presence of tank obstacles; therefore, deep foundations were dispensed with.

(4) Anti-tank Obstacles on Highways and Roads (1946-50)

Anti-tank obstacles for roads and highways were developed. The method evolved consists in destabilizing the soil under the highway and roads and covering the surface with thick soil crust which while sustaining the load of light vehicles and jeep (3 tonnes) collapsed under the weight of the tanks. On the surface there was no visible sign of any destabilization underneath.

(5) River Training with the Help of Pitched Surfaces (1942-45)

A new method evolved for training rivers and streams through central pitched islands is based on the principle of erosion close to the headworks at Sulemanki. It was also tried on actual works and on the prototype of the Satluj river, besides various models. This method aroused considerable interest in India and abroad and was hailed as a great advance on the existing methods for river training and control[11].

(6) Design of Surface Profile of Hydraulic Structures with the Help of Models (1935-50)

Efficient and economic surface profile designs of various works, such as weirs, undersluices and regulator falls were developed based on intensive model studies. Besides designs for the reconditioning of the old structures, designs for the construction of the new ones undertaken in Punjab during 1934-47 were developed.

The results were reported in about 250 special technical committee reports submitted to the government. Twelve papers were published.

(7) Research on Water Table Behaviour, Waterlogging, Salinization of Irrigated Soils together with Development of Measures to Ameliorate Waterlogging and Salinization (1952-85)

An area of 1.6-1.8 million hectares had got waterlogged in Punjab by 1955-62. The canal irrigation is not an unmixed blessing. Due to a variety of causes, water table in the irrigated tracts rises, ultimately causing waterlogging and salinity. This happened in the united Punjab as well as in the part of Punjab which remained in India after independence.

Considerable work was carried out in practically all the Doabs of the Punjab. The causes of the twin malady of waterlogging and salinity and measures to ameliorate the condition were studied exhaustively over several decades. About 35 papers on waterlogging and 10 on salinity were published. Two reports on waterlogging were prepared and submitted to the government.

Execution of extensive drainage system in the Punjab resulted in the construction of a network of drainage channels (several hundred in number) in half of the Punjab state. Some of the drainage channels were the largest ever constructed in any part of the world. Some of these channels carried a discharge of 340-400 cumecs and were 150-200 km long. These drainage channels made the Punjab rid of waterlogging.

(8) Reclamation of Saline and Alkali Land

Salination of soils generally takes place in the canal irrigated area in semi-arid tracts. In certain areas, high alkali soils also occurred. In the Indus plain, about 40,000 hectares are going out of cultivation every year on account of the formation of saline and alkali soils. Reclamation of such soils is very essential.

Work on reclamation of saline and alkali soils was taken up by Uppal after he joined the Punjab Agricultural University and economical and efficient reclamation methods were evolved. Reclamation of 30,000 hectares of saline and alkali soils per annum was done during 1954-65 with great success.

(9) Building Materials

Considerable work was carried out on building materials like soil, cement, concrete, kankar, surkhi lime pozzolana and the effect of particles size of building material on strength. The aspects covered include design of mix for mortar for use in various structures, such as canal lining, concreting of weirs, barrages, dams; bond to steel strength of concrete as affected by the use of pozzolona and entrainment of air in concrete; and requirement of concrete for different types of works. Special studies were carried out on pozzolona surkhi.

(10) Water Resources Research

Besides considerable work on the water resources of India, a museum of water resources was developed at the Punjab Agricultural University campus, Ludhiana, where data on all the rivers of northern India, water and power potential, together with their utilization are depicted. Data on damage caused by floods and droughts are also presented for a number of years.

Notable among the honours won by Uppal are the Kennedy Gold Medal (1945); Union Ministry of Irrigation and Power Gold Medal and cash award (1966 and 1967); Sir Arthur Cotton Memorial Gold Medal (1967); Central Board of Irrigation and Power Gold Medal (1967); Indian National Science Academy Award (1985); and President of India Medal (1978).

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L R Vaidyanath

During his career at the National Metallurgical Laboratory, Jamshedpur, Vaidyanath was attached to the Mechanical Metallurgy Division and was responsible for (1) developing controlled friction materials for the Indian Railways, (2) study of the characteristics of hoop steel, and (3) survey of cutlery steel in India. He conducted in-depth studies on friction and wear and carried out related simulated experiments, which gave a better understanding of the surface properties of metals and materials. He published several papers on friction and wear, and passed on the results obtained to the Railway Research and Development Centre at whose behest the work was undertaken. Under a fellowship at the University of Birmingham, UK, he helped in the development of theories for autogenous bonding of metals. One of his papers earned him Sir William Larke Medal in 1960 for the best paper published in the *British Welding Journal.*

On his return to India, he was appointed as an Officer on Special Duty for research and development in a ferro alloy industry. His research and development work led to a better understanding of the production of some of the ferro-alloys, such as ferro-manganese and silico-manganese and briquetting of coke fines. He achieved reductions in energy consumption in the manufacture of ferro-alloys and utilization of the waste products like slags, coke fines and waste gases.

During his tenure at the steel tube industry, he was responsible for controlling the consumption of the then scarce and vital metal zinc used for galvanizing. The mandatory minimum thickness of coating of zinc was achieved through studies and experimentation.

He has made significant contributions to non-ferrous metals industry, particularly to the copper and copper alloy industry. He is closely associated with the industries and research organizations in this field both in India and abroad. His studies have been on proper and effective use of copper, a sizable part of the requirement for which is met through imports. He has helped the industry in trouble-shooting and conducting research projects on metals like high conductivity coppers, primarily to achieve import substitution. A host of technical programmes are regularly arranged under his leadership.These include in-plant lecture courses and shop-floor investigtion studies, group discussions, workshops, symposia, seminars and conferences which have made significant contributions in improving processes and products. The programmes have helped the industries in conserving the scarce metal copper and also in bridging the technical gaps and improving quality of the products.

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Vaidyanath has been responsible for the introduction of new processes like continuous casting, electroforming and powder metal forming in the area of copper.

In his capacity as Director, Indian Copper Development Centre, he has been able to train up personnel in the identification of the important role of copper in various engineering applications.

As Hon. Secretary of the Indian Institute of Metals, a premier professional body in the country, he has helped in the growth of the Institute and in planning programmes of national interest.

In recognition of his distinguished contribution to the field of metals and materials, he has been elected Fellow of the American Society for Metals. He is recipient of BRALCO Gold Medal of the Indian Institute of Metals for significant contributions to Non-Ferrous Industries and Distinguished Alumnus Award of Department of Metallurgy, Banaras Hindu University.

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Sectional Committee—V : Earth Sciences
(Atmospheric Sciences, Geography, Geo-Sciences and Oceanography)

F Ahmad

Ahmad took up research after obtaining his MSc degree in geography from the Aligarh Muslim University. Shortly thereafter he was selected (January 1941) as a postgraduate scholar in the Geological Survey of India. He submitted his thesis for PhD degree in 1949. Yet, his switchover from geography to geology was firm and final. In 1951, Ahmad proceeded to Tasmania for a little over a year, worked under Prof S W Carey and obtained MSc degree in geology. Ahmad continued in the Geological Survey of India till January 1964, when he was invited to take over as Professor & Head, Department of Geology, Muslim University, Aligarh. Just prior to his superannuation, he was invited to take up, in November 1975, the post of Commissioner, Geology & Mining, Government of Jammu and Kashmir. Later, he was given the additional charge of the public sector unit, J & K Minerals Ltd. He held this dual charge till March 1981. On retirement, he joined the private sector.

While in the Geological Survey of India, Ahmad worked on the coal deposits of northern Afghanistan in 1941 as a member of Government of India's coal survey party under Dr W D West. Later, he mapped part of the trans-Indus salt range, and a part of Chaghai district in Western Baluchistan. After the Independence, Ahmad mapped parts of Vindhyan Super Group in Mirzapur district and it was his work on the Singrauli coalfield that brought to light the thick coal seams in the area, revealing it as a major coalfield. In 1954, he was transferred to the then newly established groundwater division and worked in different parts of the country on this aspect. Ahmad volunteered to join a team on glacial survey in the Himalayas and stayed on the Bara Shigri Glacier for a few weeks. Similarly, he volunteered to study the 1950 earthquake in Assam. He thus gained experience in a variety of field jobs.

Ahmad has published extensively and has to his credit one book and over 100 papers. Most of these deal with problems of continental drift and Gondwanaland; he had an important role in the revival of interest in these fields. Ahmad also studied the distribution of pre-Gondwana glacial deposits, especially in Gondwanaland. Of late, Ahmad has got involved with the earth-expansion concept and has been contributing to the subject.

His Gondwanaland research was recognized when he was awarded the International Chrestien Gondwanaland Gold Medal; he is the only Indian to be so honoured todate.

In 1972, he was elected a fellow of the Indian National Science Academy and in 1973 of the Indian Academy of Sciences.

Formerly, Professor & Head, Department of Geology, AMU, Aligarh and Commissioner, Geology and Mining, Government of J & K; *Residence* : 4 D/D II Extension, Gandhinagar, Jammu.

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R Ananthakrishnan

(1) Light Scattering

I commenced my research career at the Physics Department, Indian Institute of Science, Bangalore, in 1933 with studies in the field of light scattering. These studies, pursued for the next four years, formed the subject matter of my DSc thesis, relating to Rayleigh scattering in liquids and gases, and Raman scattering in a number of liquids and crystal powders. I was among the first few workers to study the Raman spectrum of heavy water, a rare commodity in those days. A new experimental technique using complementary filters was devised for the study of Raman spectra of crystal powders, which proved very successful for the study of several organic and inorganic substances. Raman spectra of water of crystallization in several substances were also photographed by the new technique.

(2) Solar Physics and Meteor Astronomy

I worked as Assistant Director at the Solar Physics Observatory, Kadaikanal, from 1946 to 1954. My work in solar physics covers spectrophotometric and some other studies relating to sunspots and a comprehensive study of solar prominences recorded at the Kodaikanal observatory during the period 1905-1952. An interesting result emanating from the latter study was the remarkable progression of prominence activity from the equatorial to polar latitudes on the sun, from the sunspot maximum to minimum. A diagram which I published showing this has been reproduced in the article entitled 'Structure and Dynamics of the Solar Atmosphere' by C de Jager in the *Encyclopedia of Physics* [Vol 52 (1959) 329-30].

During a period of six months that I spent at the Dominion Astrophysical Observatory at Ottawa (Canada) in 1960, I carried out some studies on the light curves of meteors utilizing the photographic records of meteor trails obtained with super-Schmidt cameras at two Canadian stations.

(3) Meteorology

From 1937 to 1971, I worked in the India Meteorological Department (IMD) from which I retired as Director of the Indian Institute of Tropical Meteorology, Pune, in 1971. Since my retirement, I am continuing my scientific work at the Institute in the capacity of an Honorary Fellow.

One of my early scientific contributions in the IMD was the preparation of an aerological diagram (tephigram) for depiction of the data of upper air soundings. This diagram is still in use in

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IMD. The following are among the topics covered in my studies and publications in meteorology: Thermal structure of the atmosphere; vertical variations of lapse rate; tropospheric inversions; haze layer in the lower troposphere; fluctuations of pressure and temperature; variability of upper winds; upper air changes associated with the southwest monsoon; diurnal variation of winds; precipitable water vapour in the atmosphere; relationship between pressure and winds at low latitudes; biennial oscillations in the equatorial troposphere; performance characteristics of radiosondes; criteria for declaring the onset of the southwest monsoon; tropospheric thermal changes associated with seasonal transitions over India; atmospheric oscillations of 4-5 day period; photogrammetric study of clouds; adiabatic generation and dissipation of kinetic energy by meridional and zonal winds during winter; tracks of cyclonic storms and depressions in the Indian seas; atmospheric tidal pressure oscillations; rainfall in India and its space-time variations.

While in service in IMD, I was responsible for the preparation of an 'Atlas of tracks of storms and depressions in the Bay of Bengal and the Arabian Sea: 1877-1960'. To meet defence needs, I organized the preparation of a publication entitled 'Climatology of Himalayas, Tibet and the adjoining areas'.

At the instance of the Madras Science Foundation, I am currently engaged in writing a book on Meteorology to serve as background reading material for +16 students. It is also my intention to devote myself to the writing of two books, one on Physical Meteorology and the other on Dynamical Meteorology. My present research interests relate to certain aspects of the physics and dynamics of the Indian monsoons.

Since retirement from service I have been associated with the University of Cochin, where I organized MSc Course in Meteorology and was also doing teaching work for seven years. I am presently associated with MSc teaching in Meteorology at the University of Poona. I have also been giving an organized course of lectures for the benefit of the junior scientific staff of the Indian Institute of Tropical Meteorology.

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U Aswathanarayana

Any fundamental study of the earth as a physicochemical system has to reckon with the formidable problems arising from not only the enormous size of the system, and the numerous and complex variables involved, but also with the vast stretches of time (running into billions of years) during which the earth processes took place. This daunting task was sought to be accomplished by the earth scientists by applying physical, chemical and mathematical tools to unravel the nature and magnitude of the earth processes and the modes of their interaction during the geological time. Radioactivity has proved to be a powerful tool in this regard, and Aswathanarayana has been a pioneer in radioactivity studies in India. Most of the work done by him and his associates has been reviewed in his recent publication[1].

(1) Radiometric Dating and Geochronology of India

Aswathanarayana initially started dating the radioactive minerals by U-Th-Pb "chemical" method, as he did not then have access to a mass-spectrometer[1,2]. All the lead present in the mineral was deemed to be radiogenic, and as it is usually so in old U-Th minerals, the errors arising from this assumption are not serious. This study resulted in the delineation of the broad framework of the Archaean orogenic cycles of India[3]. Later, isotopic methods involving the Rb-Sr and K-Ar methods of dating whole rocks and mineral separates and lead methods of dating of radioactive minerals and galenas were employed to delineate the metamorphic chronology of the Precambrian belts of India[4–9]. His notable contributions are to show that (i) the sedimentation in the Cuddapah Basin started around 1500 Ma ago, subsequent to the Eastern Ghats orogeny, about 1600 Ma ago, (ii) there had been more than one episode of charnockitization in the Precambrian terrains of South India, and (iii) the Eastern Ghats rocks were subjected to a profound and widespread metamorphic impulse around 450-500 Ma ago ("Indian Ocean Cycle").

A comprehensive synthesis of the geochronological history of India from the Archaean (ca 3800 Ma tonalites of Bihar) to the Middle Miocene (16 Ma) Himalayan orogeny, has been attempted recently by Aswathanarayana[1].

(2) Temporal, Spatial and Geochemical Evolution of Deccan Traps

The origin, geochemical heterogeneity and possible nature of the upper mantle source of the Deccan Traps have been investigated using major element, trace element and Sr isotope data, in conjunction with geologic setting and structure. A number of critical trace elements (K,Rb,Sr,Cs,Ba,U,Th,Ta, etc.,

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determined mostly by neutron activation analysis) and Sr isotopes have been used to develop petrogenetic models in respect of the Mount Girnar Complex, western India. There is evidence for the "continentalization" of the oceanic-type, low-K tholeiites. The abundance of tantalum has been used to discriminate between *ortho*- and *para*-syenites. A new type of tantalum resource (in the form of easily separable pyrochlore in microsyenite) has been identified[10,11]

K-Ar age dating and Sr isotopes have been made use of to study the temporal evolution (50-42 Ma) and magma genesis (lava flows which have undergone crustal contamination, and "pristine" lavas) of the lava sequence of the northeastern part of the Deccan Traps around Sagar, MP, India[12]. The history of effusion of the Deccan Traps was sought to be reconstructed, ranging from the earliest about 100 Ma Lower Cretaceous flows in the Dhanduka sequence, Saurashtra, Gujarat, to the waning phase of the Deccan Traps (42-31 Ma, Eocene-Oligocene) of upper flows of Koyna, Dohad, etc., with 65-60 Ma Palaeocene peak which is most widespread, particularly in western India[12].

(3) Stable Isotopes and Chemical Indicators of Palaeo-Environments

Chemical characteristics (major elements, trace elements and radioactive elements, and particularly Co/Ni, V/Cr, Th/U ratios) and stable isotopic abundances ($\delta^{13}C$ and $\delta^{18}O$) have been used in conjunction with geologic setting, sediment characteristics, sediment structures, etc., to delineate the palaeoenvironments of the Late Proterozoic Chhattisgarh Basin, India. It has been shown that the Charmuria Limestone Formation (490 m thick) was formed in a subtidal environment, with a turbidity level high enough to prevent the development of stromatolites. The younger Chandi Limestone Formation (670 m thick) was formed in an open, intertidal environment, marked by the abundant development of SH-V stromatolites[13].

(4) Geochemical and Stable Isotope Study of the Abnormal Fluoride Waters of Northern Tanzania

The endemicity of skeletal fluorosis in parts of northern Tanzania is attributed to the ingestion of more than 20 mg/day of fluoride, largely through the drinking of highly fluorous waters (with about 10 mg/litre of F^-) and partly through eating "magadi" (highly fluoridic, sodium bicarbonate encrustations used as salt) and food. Geochemical and stable isotope (δD and $\delta^{18}O$) techniques have been employed to trace the source of high fluoride concentrations (principally alkali basalts, nephelinites, carbonatites, with F sometimes being present in the ashfalls in the form of highly soluble villiaumite) and the pathways of movement of fluoride through soils, waters (surface, ground, spring, pond, etc.) vegetation and food, to man[14].

(5) Geochemical Dispersion Patterns of Radioactive Elements and Base Metals

A large number and variety of terrestrial materials (rocks, soils, waters, plants, sea-floor sediments, etc.) have been examined for their radioactivity, and, in conjunction with relevant geochemical data, have been related to the mode and environment of formation of the material concerned.

On the basis of Th/U, U/K, K/Rb, $Fe_2O_3/FeO+Fe_2O_3$, Sr-86/Sr-87, a petrogenetic model was developed for the Closepet Granite of Karnataka state. It involved a two-stage history: (i) palingenesis, starting from the 2600 Ma Peninsular Gneiss, and (ii) metasomatism involving enrichment in K, Pb, Rb, Th, and depletion of Sr, Cs, etc.[15]. It has been shown that Th/U and U/K ratios are capable of being used as aids in prospecting for uranium and thorium deposits in peninsular India[16]. On the basis of contents of U, Th, K, etc. (determined by neutron activation analysis) of several mantle-derived rocks, models have been developed for the mineralogical, chemical and isotopic composition of the model upper mantle[17]. The primary and secondary dispersion patterns of base metals in the Mamandur prospect, Tamil Nadu, have been delineated and a possible base metal indicator plant (*Waltheria indica*, Sterculiaceae) has been identified[18].

Aswathanarayana[19] developed a comprehensive model to account for the pattern of distribution of the monazite-bearing heavy mineral sands along the west and east coasts of India. The pattern is a consequence of the operation of the following factors cumulatively: lithology, structure, weathering and erosion of the geological formations constituting the primary provenance, the geomorphic history and physiography, the gradient of rivers and the quantum of river discharge, the nature of the alongshore currents, events leading to the emergence of land and flooding of river valleys, etc.

(6) Geochemistry in Health and Disease

The natural distribution (in rocks, soils, waters, airborne dust, vegetation, etc.), geochemical pathways, nature of the ligands and interactions, geochemical and bio-availability, abundances in food, drink, etc. of certain toxic elements, have been used to understand the etiology and epidemiology of cancer, kidney diseases, fluorosis, etc. in the Tanzanian context[20].

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S B Bhatia

Bhatia, one of the prominent micropalaeontologists of the country, has made significant contributions in the fields of micropaleontology and biostratigraphy in India. A PhD in micropalaeontology from London University (1953), his contributions cover wide ranging groups of microfossils, particularly foraminifera, ostracoda and charophyta.

His pioneering work on Recent Foraminifera of Western India and of the Late Paleogene sediments of the Isle of Wight, England, have been quoted widely in textbooks on micropalaeontology (Jones, 1956; Pokorny, 1963; Boltovskoy and Wright, 1976). The Permo-Carboniferous foraminiferal fauna described by him from two localities of Madhya Pradesh opened new vistas in the study of paleogeography of the Indian subcontinent during its early relationship with the Gondwanaland.

Bhatia is also credited with pioneering work on the Tertiary and Quaternary ostracoda of the Indian subcontinent. In his paper on the Recent Ostracoda of the Karwar coast, he described three new genera/subgenera which are endemic to the Arabian Sea region. The paleogeographic implication and possible migration routes of some of the frashwater quaternary ostracoda of the Indo-Gangetic plain were presented by him at the Eighth International Symposium on Ostracoda at Houston in 1982.

The well-known Neogene and Quaternary Siwalik and Karewa groups of the Himalayas received early attention of Bhatia, particularly with regard to their ostracoda and charophyta. The biostratigraphic significance of the charophytic flora of the Siwaliks was discussed by Bhatia in a paper presented by him at the First International Conference on Pacific Neogene Stratigraphy at Tokyo in 1976. His work on the paleogeographic implications of the ostracoda and charophyta of the Inter-Trappean beds of Peninsular India shows lack of endemisms, a fact at divergence with the widely accepted Plate-Tectonic model. A new terminology for describing the morphological features of freshwater Ilyoyprid ostracodes has also been suggested in his paper on Karewa Ostracodes. The first ever record in the world of Callovian charophyta is also credited to him.

Among other significant works of Bhatia which are of great biostratigraphic importance mention may be made of the ones dealing with the presence of passage beds between the Subathu and Dagshai formations in the Simla Hills (indicating the absence of any unconformity in the sequence) and the proposal of a new

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stratigraphic unit—Dalmiapuram Formation—in the Cretaceous Stratigraphy of South India.

Besides his interests in paleontology, Bhatia has also important papers to his credit on the discovery of a stone age site in the Indian desert, Greywacke and Secretion Pegmatites.

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V L S Bhimasankaram

Bhimasankaram's contributions to geophysics have been essentially in two directions, viz. gaining knowledge of the earth, and in exploration of minerals, oil and gas and other subsurface economic deposits. These can be summarized under the following heads: (1) Paleomagnetism and rock magnetism, and (2) Geophysical prospecting technology.

(1) Paleomagnetism and Rock Magnetism

Having been initiated in paleomagnetism and rock magnetism in the laboratory of Prof. P M S Blackett, Nobel Laureate, at the Imperial College, London, Bhimasankaram has studied a large number of Indian rocks, in particular the Deccan Traps, for their paleomagnetism[1–3]. This study led to the establishment of the history of the geomagnetic field through Deccan Trap volcanism, and location of horizons of geomagnetic field inversions. The results further supported the theory that the earth's magnetic field reverses itself every few million years.

Bhimasankaram has also studied in detail the magnetic properties of natural and artificial pyrrhotites and has established the possibility of partial magnetic self-reversal in pyrrhotite in the laboratory due to electrostatic interaction of two magnetic components with differing curie temperatures. The work is of great significance in the context of attempts of geophysicists in demonstrating magnetic self-reversals in the laboratory[4,5].

(2) Geophysical Prospecting Techniques

In exploration geophysics, one studies, with appropriate physical instruments, the spatial variations in some particular physical field or parameter associated with the subsurface under investigation. The presence of inhomogeneities, such as ore deposits, structures containing oil and gas, etc., causes deviations in the field measured from that one would except if these inhomogeneities were not present. These deviations, termed as geophysical anomalies, form diagnostic indicators, and are interpreted in terms of the location, size, shape, depth, etc., of the causative body. On the basis of the physical field or parameter measured, we have several groups of methods in exploration geophysics, such as gravitational, magnetic, electrical, electro-magnetic, seismic, radiometric, geothermal, etc., each of which has a number of variants.

Bhimasankaram's contributions to geophysical technology have been in different directions: (i) Development of methodology and applications, (ii) Development of geophysical methods, (iii) Development of laboratory and field equipment, (iv) Theoretical and practical

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approaches in inversion problems of interpretation, and (v) The necessity of an integrated geophysical strategy for exploration of mineral deposits.

(i) Bhimasankaram has been responsible for the development of geophysical methodology for locating ground water in different geological terrains, such as hard rocks, sedimentary rocks and alluvial regions, and has thus contributed to the growth of the new subject of groundwater geophysics[6–8].

He has studied in detail the magnetic properties of manganese ores and has shown that within a short range of non-stoichiometric compounds between hausmannite and magnetite, the magnetic properties vary in a complicated manner. These findings were useful in explaining the complex field magnetic anomalies over manganese deposits[9,10].

(ii) Bhimasankaram has contributed significantly to the development of a geophysical method called piezoelectric method. The method involves utilization of the piezoelectric property contrasts between the causative body (quartz or pegmatite body) and the surrounding and overlying rocks. Here, an elastic impulse is produced in the ground and the electrical field developed along the profile is investigated. Bhimasankaram and his colleagues studied the piezoelectric properties of a few representative rocks and showed the possibility of using this method for locating hidden quartz and pegmatite veins, which sometimes contain valuable and strategic minerals[11,12].

(iii) Bhimasankaram and his colleagues have developed a few important geophysical field and laboratory techniques and equipment. Mention may be made of the following:

(a) A ground version of the transient electromagnetic survey technique was developed and introduced in the country by Bhimasankaram and his colleagues[13,14].

(b) Using indigenously produced proportional counter, an XRF analyser was developed and the methodology of analysis of some important ores was worked out[15]. For the first time in the country, gamma-ray transmission and scatter technique have been developed for the rapid and non-destructive determination of ash content in coals[16].

The current research work is directed at field application of radon surveys in uranium exploration and development of nuclear geophysical methods for on-line field studies for evaluation of mineral deposits.

(c) Bhimasankaram and his colleagues developed a dipole induction profiling equipment (with focussing), useful for studying the apparent resistivity of the ground. A specific feature of this equipment is the possibility of reducing the influence of the top layer of the earth (where minor geological inhomogeneities cause noises) and to focus the study to an intermediate level. The equipment was found useful for groundwater studies in granitic terrain.

(d) Bhimasankaram was responsible for routine employment of geophysical logging techniques in ground water exploration and exploitation. He, along with his colleagues, developed indigenously a shallow borehole logging equipment (with complex measuring devices) which has been found to be very useful in ground water and mineral studies up to about 100 m depth[17].

(iv) The ultimate objectives of geophysical exploration activity being the location of economic subsurface deposits, inversion of the measured geophysical anomalies in terms of geological inhomogeneities assumes great significance. Bhimasankaram has contributed to the geophysical inversion theory in the following directions:

(a) He and his co-workers developed mathematical-statistical inversion techniques of inter-profile correlation and auto-correlation[18].

(b) Using Fourier transforms, numerical methods were proposed for inversion of geophysical data due to a number of bodies, such as trapezoidal prisms, two-dimensional circular cylinders, isosceles triangular bodies, inclined dykes, etc.[19–21].

(c) He and his colleagues developed algorithms for ground water basins for use in microprocessors.

(d) He and his colleagues solved direct and inverse problems of transient pulse induction method of prospecting for bodies such as two-layer earth, high conductivity overburden, etc.[22,23].

(e) Since each of the geophysical methods is applicable in a particular physico-geological environment, and hence has its own limitations, the success of geophysical prospecting can be enhanced by utilizing a rational complex of different geophysical techniques. Bhimasankaram has put forth this idea strongly and pointed out the necessity of developing integrated geophysical inversion technology, through a series of lectures and publications[24].

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G Bomford

Elected as a fellow of the National Institute of Sciences of India (now Indian National Science Academy) in 1935, Bomford obtained his DSc from Oxford University. He was Royal Engineer (1971-48), seconded to the Survey of India (1921-48); Brigadier (1945-46); Reader in Survey and Geodesy (1948-66), Oxford; and Reader Emeritus (1966).

The studies conducted by Bomford were related mainly to the form of the geoid, initially in India, and later in Asia, Europe and Africa.

Bomford is a member of the Royal Astronomical Society, Geological Society (London) and Royal Institution of Chartered Surveyors. He was President, International Association of Geodesy (1963-67); and President d'honneur, International Association of Geodesy (1967); and Honorary Member, RICS. He was awarded the Order of the British Empire in 1946.

Selected Publications

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Mihir K Bose

Significant contributions have been made by Bose in the areas of petrology, mineralogy and geochemistry. His research activities mark a new trend and outlook in the studies of Indian igneous rocks and on the whole his contributions have helped immensely in getting a deeper understanding of the geological history of India with reference to magmatism. During the first half of this century, petrological studies were confined to classical descriptions of rocks in mega and micro scales. At the turning point to the second half of this century, a group of workers realized the inadequacies of such studies and also got attracted to detailed structural analyses. Bose was one of those who coupled detailed mineralogical, chemical and structural investigations on igneous emplacements with the classical petrographic approach. He has repeatedly demonstrated that integrated studies on structural geometry, mineralogy and geochemistry are essential for having a proper perspective on origin and evolution for any magmatic emplacement.

Bose was initiated to hard rock geology by Prof. S Ray, at the Geology Department of Presidency College, Calcutta, during the late fifties. Later, he got further impetus for mineralogical and geochemical research from Prof T F W Barth at the University of Oslo, Norway, where he worked under a post-doctoral fellowship during 1966-67. Immediately after postgraduation, Bose joined the Department of Geology, Presidency College, Calcutta, and carried out studies on parts of Singhbhum granite body, mafic and ultramafic minor intrusions and the Kolhan basin. In later years, he carried out detailed geochemical studies on ultramafic mafic intrusions of Singhbhum in collaboration with Prof G G Goles of the University of Oregon, USA.

Intensive field and latoratory investigations by Bose brought out a unique alkaline magmatic suite near Koraput in Orissa. Gradually, he extended his studies to other alkaline complexes, viz., Sivamalai suite of Tamil Nadu, Kunavaram-Rudramkota and Elchuru plutons of Andhra Pradesh and Mount Girnar complex of Gujarat, Mer-Mundwara plugs of Rajasthan. At intervals, since 1959 to date, Bose has been investigator-in-charge for several research projects sponsored by CSIR and UGC. These intensive studies enabled Bose to publish a wealth of data on chemical petrology, crystal chemistry and differentiation history of a number of alkaline complexes of India. He studied the structural states and trace element contents of alkali feldspars from Indian magmatic suites and demonstrated the role of perthite as a subsolvus temperature indicator to locate transition temperature of K-feldspar polymorphs. In a recent study on comparative geochemistry of three alkaline complexes from Eastern

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Ghats belt, he has shown the utility of inter-element correlation. As an expert, Bose chaired a symposium on alkaline rocks at the 24th International Geological Congress (1972) held at Montreal.

During the last decade, Bose has extended his studies on gabbro-anorthosite and mafic-ultramafic complexes of the Eastern Ghats Precambrian belt. Detailed structural and petrological investigations have now been carried out on layered complexes of Chimal Pahad, Chimakurti, Kondapalli in Andhra Pradesh, and Torappadi complex in Tamil Nadu. One of the important achievements of Bose has been the establishment of a probable "event stratigraphy" along the Eastern Ghats Precambrian belt and identifying the anorthosite emplacements, each with lithotectonic characterization of its own. A highly significant finding has been the complexly deformed high calcic layered anorthosite complex and mafic ultramafic layered sheet interleaved with tonalitic rocks, which may offer clues to the existence of Archaean blocks in the Eastern Ghats belt.

Bose's studies on volcanic associations embrace the plug-like bodies and associated lavas of western Deccan volcanic province. Tectonic framework of this volcanic province in the light of plate tectonic concept has been discussed by him elaborately and a probable site of plume activity has been located. A recent significant contribution of Bose has been the identification of a fossil marginal basin in the Singhbhum Precambrian belt. This model is based on a plate tectonic concept and is supported by intensive geochemical studies on the Dalma volcanic suite.

Bose represented India in the Subcommission for Systematics and Nomenclature of Igneous Rocks, instituted by IUGS. Lately (1982), he worked at the University of Leicester and Bedford College, University of London under INSA-RS programme. He served the Sectional Committee (V) of INSA during 1982-84. Besides being a fellow of the Indian Academy of Sciences, Bose is a recipient of S S Bhatnagar Prize (1976) in Earth Sciences and of National Minerals Award (1972). He was editor of the Indian Journal of Earth Sciences for seven years during 1976-82.

Bose plans to devote more time in the future to teaching at both undergraduate and postgraduate levels, to make the students conscious about both science and society. Researches in earth sciences in this country, according to Bose, have not been able to make any breakthrough and there is no hope for this in the near future, unless attention is paid to the base of the scientific community.

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P K Das

My line of specialization has been atmospheric dynamics. More specifically the main areas of my interest have been (i) cloud physics, (ii) numerical models to simulate different facets of the Indian summer monsoon, and (iii) mathematical simulation of wind-driven ocean circulations on different scales.

(1) Cloud Physics

In the early part of my career, I was interested in the hydrodynamic flow past small spheres at low Reynolds numbers. This topic was relevant for finding out the rate of growth of small cloud droplets by coalescence. In this manner one could find out approximately whether coalescence could eventually lead to the development of a precipitating cloud. In view of the airflow past a small sphere falling freely under gravity, a small droplet was able to capture only a small fraction of the other droplets coming in its path. This is now known in meteorological literature as the 'collection efficiency' of a drop. Prior to my work, computations of the collection efficiency had treated small drops as point sources coming in the path of a large collector drop. As my computations took into consideration the finite size of both the collector and the colliding drop, it led to better estimates of the collection efficiency.

I later extended my computations to find out the change in the spectrum of cloud droplets by the process of coalescence. This enabled estimation threshold values of (a) the concentration of drops in specified ranges of drop size, and (b) the liquid water content of a cloud that was required for precipitation to occur.

(2) Monsoon Dynamics

My early work in this area was concerned with the deflection of air by a large mountain range, such as the Himalayas. Earlier work on this topic by an eminent Indian mathematician, Dr S K Banerji, had not considered the thermal structure of the atmosphere while computing the deflection of air. I included the thermal stratification, albeit approximately, in my work. This work was later extended so as to evaluate the amplitude of stationary waves over a heat source. It is now recognized that the Indian summer monsoon represents a source of heat that affects atmospheric circulations on planetary scale. This generates stationary waves that propagate in both horizontal and vertical directions of planetary waves. It provided an estimate of the vertical flux of heat from the lower to the upper atmosphere under different conditions of thermal stratification.

In a subsequent study, I computed the pattern of heat sources and sinks that was needed to maintain the summer monsoon in a steady state over India. This was based on a mathematical model in which

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the atmosphere was divided into 10 discrete layers, and the governing equations were solved for each layer with a patch at the interface between adjacent layers. This work revealed a source of heat over the north-eastern part of India, and a heat sink over north-western India. Subsequent field experiments indicated that the heating/cooling rates postulated by theory agreed with the observations made by radiometersondes over different parts of India. These observations were repeated with radiometersondes during the international Monsoon Experiment (Monex) in 1979. The observations again supported the predictions made by the theoretical model. This work led to the recognition of cellular motion, with east-west orientation, which has a significant impact on the monsoon circulation over India. It was named a "Walker cell" in honour of Sir Gilbert Walker, an eminent scientist who had helped to bring to the notice of Prof. G H Hardy the work of the celebrated Indian mathematician Ramanujan. The Walker cell postulated rising motion of air over north-eastern India, which was accompanied by subsiding air over the semi-arid regions of north-western India.

The work on building a mathematical model of the monsoon was later extended by me and my collaborators to cover other interesting features of the Indian summer monsoon.

For many years, it was thought that a zone of low pressure over northern India, known as the Monsoon trough, was created by the alignment of mountains and topographic barriers around the Indian subcontinent. Sensitivity tests with a mathematical model indicated that this was not necessarily the case. Numerical solutions of the model indicated that imbalances in the earth-atmosphere radiation balance were more relevant for the creation of the monsoon trough. The model also indicated that the movements of the trough were guided by changes in the reflective power of the earth's surface. This result is relevant, because short period changes in the reflective power could be brought about by spells of heavy rainfall during the summer monsoon.

It had been conjectured that monsoon depressions in the Bay of Bengal were activated by tropical cyclones in the China Sea and the adjacent areas of the Pacific Ocean. Outputs from the model indicated that a monsoon depression could not be the outcome of downstream amplification of westward propagating waves in a homogeneous (barotropic) atmosphere. The thermal structure of the atmosphere, especially warming by the release of latent heat during condensation, was important.

This mathematical model formed the first attempts at prediction, by numerical methods, of upper winds over India on real time by the Meteorological Department of India. The results indicate reasonably good forecasts in regions that are not too near the equator. Further improvements are now in progress.

For many years now long range prediction of monsoon rainfall over India has been based on multiple regression equations which seek to find an association between monsoon rain and other antecedent features, such as the upper air temperatures over India in the pre-monsoon summer months. The difficulty with this technique is that the intensity of a statistical association (measured by correlation coefficients) changes with time. Consequently, I have assisted in the design of autoregressive (ARIMA) models, whose coefficients show lesser fluctuations with time. This work is now in progress.

(3) Storm Surges

Every year, the Indian coastline is hit by tropical cyclones of considerable intensity. The maximum damage by a tropical storm is caused by coastal inundation. This happens because the strong winds associated with a cyclone lead to a sudden increase in sea level when the cyclone strikes the coast. The rise in sea level is usually referred to as a storm surge.

The amplitude of a surge is determined by five factors: (i) the geometry of the coastline, (ii) depth of the sea near the coast, (iii) speed and direction of storm movement and winds, (iv) interaction with tidal currents, and (v) river discharges near estuaries.

I have designed a model to predict the intensity and extent of a storm surge induced by storms moving along different tracks over the Bay of Bengal. This is now used by the Meteorological Department of India to predict the occurrence of a storm surge, its amplitude and its horizontal extent, whenever a cyclone strikes the eastern coast of India.

Improvements have now been made by others with better representation of coastal geometry and tide-surge interactions. A feature on which further research is in progress concerns the winds associated with a tropical cyclone. Hitherto, models have considered invariant cyclones in which the wind field is uniquely determined by the pressure drop between the outer periphery of the storm and its centre. This is not realistic, because the wind field will change as the cyclone moves from one location to another along its track.

(4) Future Programme

An interesting feature of the onset of the summer monsoon is the cooling of the Arabian sea before the monsoon winds set in; the observed decrease in sea surface temperature in May each year is 3-4°C. Two possible mechanisms have been suggested to explain the observed cooling, namely (i) an increase in evaporation brought about by an increase in solar radiation over the Arabian Sea, and (ii) upwelling off the eastern coast of Africa.

There exists a narrow but intense ocean current off the east coast of Africa, which reverses its direction each year. The reversal is closely linked with the reversal of monsoon winds. This is known as the Somali current.

I am working on designing a model to explain the observed cooling of the Arabian Sea before the onset of the monsoon. The model, it is hoped, will indicate how ocean currents respond to the strength of the monsoon, and how much heat is exported out of the Arabian Sea prior to the monsoon's onset. It could provide the basis for an ocean-atmosphere coupled model for monsoons.

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B G Deshpande

After obtaining his master's degree in geology from the University of Bombay, Deshpande started his career in the Geological Survey of India in 1936 at Calcutta. He carried out geological mapping for some years and also worked with the petrological section of the Geological Survey of India advising on the uses of minerals in industries. He investigated many commercial deposits of economic minerals in the country. During the second world war, he was deputed to the Sind-Punjab-Baluchistan sector and was entrusted with search and development of strategic minerals required for military operations.

In 1939, he joined the Assam Oil Company at Digboi for training and gaining experience in petroleum technology. There, he carried out geological mapping and gave geological support for drilling for oil. This was a rare opportunity to get acquainted with oil exploration in India.

In 1940, the Geological Survey started studies in engineering geology and groundwater. Deshpande was attached to this section and studied many areas in the country for groundwater potential and contributed several papers in this section. He obtained his PhD in hydrogeology in 1953. He is still engaged in this field as one of his specializations.

In 1945, Deshpande was deputed by the Government of India to the University of Melbourne in Australia for postgraduate studies and gaining practical experience in several mining areas in that country. Almost all the important mining centres in the country were visited.

He was a member of a team sent by the Geological Survey of India to investigate the earthquake which occurred along the Makran Coast on the night of 27 November 1945. This earthquake had disrupted the vital communication between India and UK. The outstanding feature of this earthquake was the emergence of four new islands rising 40-50 ft above the sea level and constituting a hazard to navigation in these parts.

The groundwater resources of the alluvial tracts of Gujarat were studied by him during 1948-50 with a view to arriving at the sub-surface geology and the possible accumulation and movement of water in the sub-surface. The study also brought out the possibility of the extension of the early Tertiaries exposed on the flanks of the basin towards the centre of the basin. This study suggested the possibility of the occurrence of petroleum in the central and deeper parts of the Cambay basin, which today is our main oil producing region.

In 1952, Deshpande joined the Indian Bureau of Mines at Delhi as Deputy

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Director (Research). He made notable contributions towards beneficiation of minerals and ore dressing of several important mineral occurrences in India. He played a prominent role in establishing the availability of raw materials for the then proposed Bhilai steel plant.

In 1956, Deshpande joined the Oil and Natural Gas Commission, where he made notable contributions to the exploration for oil in Cambay basin, Punjab, Ganga Valley, Rajasthan, Godavari Valley and parts of Assam. Among his contributions is the initiation of exploration and eventual success in finding oil in the Cambay basin. He presented a paper at the ECAPE Conference on Mathematical Strategy for Exploration of Oil in the Cambay basin.

Deshpande attended five world petroleum congresses (1959, 1963, 1967, 1971 and 1975) is different countries and contributed several papers. In his Birbal Sahni Memorial Lecture he dwelt on the 'Growth of ideas in generation, migration and accumulation of oil in the past 25 years'. The earthquake at Koyna on 11 December 1967 caused grave concern in the State of Maharashtra. The Oil and Natural Gas Commission felt concerned about the geological disturbances along the west coast and deputed Deshpande on the Koyna Earthquake Committee for investigation, especially from the point of view of oil prospects in the area. He retired from the Oil and Natural Gas Commission in December 1969.

He joined the University of Poona as Professor of Geology in June 1970 and guided several students in research in groundwater leading to the degree of PhD. He was elected President of the Geology and Geography Section of the Indian Science Congress in 1971 and delivered his Presidential Address on 'Reaching for oil in India'. He retired from the University of Poona in October 1976. In 1977, he joined University of Dar es Salaam, Tanzania, as Professor of Geology and continued there till March 1983. He contributed several papers on groundwater potential of different parts of Tanzania. He made two water wells to alleviate the acute shortage of water on the university campus. He delivered Professorial Inaugural Lecture on 'Story of Petroleum' which was published by the University in 1978.

On return to India in April 1983, he joined the Maharashtra Association for the Cultivation of Science, Pune as Hon. Professor of Geology. He worked on the project 'Some aspects of prediction of earthquakes, especially the behaviour of animals, plants and human-beings as precursors of earthquakes'. His study covered other aspects of earthquake science, such as spread of education about earthquakes, preparedness by the people for reducing the damage to life and property and creation of social awareness in meeting this natural hazard. Imparting of knowledge on various aspects of earthquakes to the people, especially in the earthquake-prone areas, is indispensable to ensure that they react rationally before and during an earthquake, and thereby reduce the damage to life and property to the minimum. His book '*Earthquakes, Animals and Man*' has been submitted to the Department of Science and Technology, Government of India.

Deshpande was elected a fellow of the INSA in 1966. He is also a founder fellow of the Maharashtra Academy of Science and a member of several societies in earth sciences.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

A K Dey

Dey has worked in all major branches of geology from extra-terrestrial bodies like meteorites to most of the terrestrial materials.

The Valudavur Meteorite

Dey conducted extensive studies[1] on this meteorite which fell in a paddy field at Valudavur, 10 miles north-west of Pondicherry on 30 October 1944. In appearance and chemical composition, the meteorite was shown to resemble the Kroonstad (Cronstadt) meteorite falling under group II of G T Prior's classification.

Rock Types of the Eastern Ghats

The khondalite suite of sedimentary rocks and associated charnockites are the main types of the Eastern Ghats in India. These rocks exhibit every variety of structure and texture, and grade imperceptibly to garnetiferous sillimanite-bearing schists and gneisses through rocks that appear to be distinctly granitic. The work of Dey[2] has provided some support to J A Dunn's concept of diabrochomorphism (diabrochos = to soak, to permeate, to saturate or to wet).

Gold Deposits

On two occasions (1935-1939 and 1967-72), in connection with projects sponsored by the Council of Scientific and Industrial Research, Dey worked in Jashpur, now in the Raigarh district of Madhya Pradesh, where gold occurs in the area lying south of Lat 22°39′ in the drainage basin of the river Ib and its tributaries[3]. Dey traced the source of gold to quartz veins traversing the gneissose granite country rock.

During 1970-71, an area of 3 sq miles between Barjor and Hatigara near Tangargaon was prospected for gold in quartz veins by the Directorate of Geology and Mining of Madhya Pradesh under the supervision of Dey and gold values assaying from 0.1 to 0.3 g/m tonne were found.

Buchanan's Laterite of Malabar

Opinion has been expressed that the term laterite should be used in the original sense, namely, for materials of the type described by Buchanan, and quarried at Angadipuram in Malabar for use as a building stone. Buchanan coined the term laterite to denote the physical property of being readily shaped into bricks and blocks when freshly quarried. The chemical composition is not strictly relevant, the type locality being very important. Dey did have the chemical analysis of representative samples of laterite collected with a view to studying the composition of the summit material *vis-à-vis* the softer vermicular below[5]. On the whole, it has been found that the top pellety layer from Malabar is definitely

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more laterized than the softer vermicular material below, but even then laterization is not complete in the same sense as for the laterites of the Deccan trap. If Fermor's terminology is accepted, none of the samples of the lateritic material from Malabar represents 'fully formed' laterite.

$FeO(FeV)_2O_3$, a New Vanadium-bearing Mineral

This mineral, named Coulsonite by J A Dunn and Dey[6], was discovered near the southern borders of the Dhalbhum subdivision of Singhbhum, Bihar and extending into Mayurbhanj in Orissa. It has been found in many places in India, and abroad, for example, Ontario in Canada, New York State in USA, etc. The mineral is of strategic importance for making special steels. It occurs in very close association with basic and ultra-basic rocks, sometimes altered to serpentines, more often to epidiorite, but, as a rule, little changed from the original basic gabbro of which it is a magmatic segregation.

Miocene Mollusca from Quilon, Kerala

Dey[7] found the fauna to show distinct affinities with those of the Gaj and Karikal beds of India, and several species to be identical with those of the Miocene and Pliocene of Java. There is hardly any doubt that this fauna is of the same age as that of the Miocene of Sri Lanka, since such species as *Taberina malabarica* (Carter) and some of the typical Gaj forms found in Quilon have also been recorded from Sri Lanka. But whereas in Quilon the individuals are dwarfed, in Sri Lanka they are thick, robust and full-grown. Vredenburg [*Rec geol Surv India*, **55** (3) (1923) 110-18] described these species of *Placenta*, viz. *P. birmanica*, *P. promensis* and *P. sindiensis*, from the Miocene of India and Burma, which with a more or less developed pair of subsidiary ridges have an irregular platform between the primary resilifier. For these he proposed the term *Indoplacuna*, constituting a new sub-genus of *Placenta*. Although the fossil from Quilon agrees well with *Indoplacuna* in having the platform between the resilifier ridges, it cannot be strictly included under that sub-genus in as much as it has no distinct secondary pair of resilifier ridges; moreover, the arched resilifier forms just less than a right angle. These features point to a further stage in the evolution of *Placenta* than had been reached by *Indoplacuna*.

Vrendenburg (*ibid*, p 110-18) considers *Indoplacuna* to be extinct, not having survived the Middle Miocene (*ibid* p 117). The occurrence of *Placenta lamellate* (a form intermediate between *Indoplacuna* and *Placenta*), therefore, suggests that the Quilon limestone bed is younger than Middle Miocene.

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S K Ghosh

The early research activity of Ghosh at Jadavpur University, Calcutta, involved the elucidation of structural and metamorphic histories of the Precambrian rocks in such areas as the Kuilapal terrain in West Bengal, the Nathdwara area in Rajasthan and the Simla area in the Himalayas. In subsequent years, he has been interested mostly in the mechanics of development of different types of geologic structures. He collaborated with Hans Ramberg of Uppsala University, Sweden, to study the structures of the Norwegian Caledonides and conducted a series of investigations on the experimental deformation of test models. These studies led to the interpretation of the phenomenon known as "refraction of cleavages". The experiments also gave an insight into the mechanics of superposed buckle folding and of interfering folds in a regime of constructive deformation. The buckling experiments with multilayered models elucidated the mechanism of development of folds in layered rocks.

The laboratory for Experimental Model Deformation in the Jadavpur University, Calcutta, was set up by Ghosh in 1968. The theoretical and experimental studies carried out include (a) theoretical analysis on the wavelengths of noncylindrical buckling folds, (b) physical factors which control the shapes of natural folds, (c) strain distribution over superposed buckling folds and manner of reorientation of early lineations by later folding, and (d) theoretical and experimental investigations of the problem of deformation of conglomerates.

During 1974-1978, Ghosh worked on the problem of rotation of rigid and deformable geologic bodies and on the different types of geologic structures which develop by the dissimilar rotations of the stiffer inclusions and the passive markers of the softer matrix.

His recent investigations cover diverse aspects of structural geology, viz. (a) the problem of slip along axial plane schistosity, (b) experimental investigation of pene-contemporaneous folding of soft sediments, (c) tectonics of the Jharia coal basin, (d) sheath folding in shear zones of the Kolar schist belt, (e) lineation pattern produced by simultaneous buckling and flattening, and (f) the structural history of the Singhbhum shear zone.

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K Gopalan

Gopalan has specialized in the application of nuclear physics to the elucidation of long-term terrestrial and extraterrestrial processes. Every rock, be it a part of the earth or moon or a small chunk of matter from deep space coming to us in the form of meteorites, incorporates at its formation a natural clock in the form of trace elements like uranium and rubidium which decay with time into stable elements like lead and strontium, respectively. Using sensitive and sophisticated mass spectrometers built by him to measure the extremely small quantities of the accumulated decay products in meteorites, lunar samples and terrestrial rocks, Gopalan determines the time of not only their formation but also any subsequent disturbances experienced by them.

His research addresses basic questions on the origin and evolution of the earth. For this, he tries to decipher the complex evolutionary record of the earth preserved in a fragmentary manner only in the continental crust, as the much larger oceanic crust is renewed by the dynamic earth processes too rapidly to contain any record beyond the last 200 million years. As far as we know, the continental record, though long, does not extend to the very beginning of the earth's history, making it necessary to look at primitive objects like the meteorites or less evolved planets like the moon for clues to the embryonic stages of the earth, in particular, and the solar system, in general. Gopalan has adopted such an integrated approach.

After getting his PhD from the Indian Institute of Science, Bangalore, in 1966, he proceeded to the University of California, Los Angeles, and did pioneering work on the times of formation of the family of stone meteorites, which clearly showed that planetary formation was a relatively sharp event about 4600 million years ago[1-4]. Because of his special expertise in handling the precious and scarce meteorites, NASA inducted him for the study of the first batch of the moon samples in 1969. Even this early study showed that the moon was not still-born, but remained a dynamic body for at least the first 1500 million years of its history[5].

Gopalan joined the Tata Institute of Fundamental Research, Bombay, on his return to India in 1970 to investigate the residence time of meteorites as small planetary debris in the solar system. Most stony meteorites do not survive more than a few million years as independent objects before being captured by the earth[6]. On his moving to the Physical Research Laboratory, Ahmedabad, in 1973, he took up reconstruction of the evolutionary history of the Indian subcontinent, as some of its prominent geological features like the Himalayas, the Deccan Plateau of

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Central and Western India and the ancient basements exposed in Karnataka, Bihar and Rajasthan, provide unique opportunities to decipher the style and mechanism of crustal evolution through geologic time. Some of the recent significant achievements of Gopalan and his coworkers are: the recognition of crustal components dating back to 3500 million years near Udaipur in Rajasthan and hence representing one of the few surviving remnants so far known of the earliest crust of the earth[7,8] and the demonstration that the Deccan lava pile covering as much as 500,000 sq km of the Indian land mass erupted about 60 million years ago from fractional melting not of a virgin upper mantle beneath it, but of one which has had a prior history of crustal contribution[9–11]. There appears to be no fundamental difference between the mantle reservoirs giving rise to the thin veneer of volcanic rocks throughout the oceanic crust and those supplying the much less voluminous volcanic rocks on the continental crust. As a new area of activity, Gopalan has assessed the potential of the isotopic abundances of hydrogen, oxygen and carbon in plant materials as a source of climatic information. For this, he has studied the annual growth rings of very old trees growing in Kashmir and other regions[12].

Gopalan moved to the National Geophysical Research Institute, Hyderabad, in 1984 to organize a modern isotope geology laboratory to investigate some fundamental problems in earth sciences, such as the chronologies of crust formation and the nature of the precursory materials (mantle or pre-existing crust) for the chemically distinct and physically separate rocks exposed on the Indian lithosphere.

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B L Gulatee

(1) Geodetic Triangulation

Charts of data on geodetic triangulation for different stations distributed uniformly all over India obtained using precision theodolites are published in the Annual Geodetic Reports of the Survey of India. An integral part of this primary survey is the measurement of precision base-lines (6-10 miles long) suitably distributed over the country. In one of his early publications[1], Gulatee discussed the ramifications of this work, involving as it does, maintenance of special standards of length and their periodic calibration against European standards. Things are complicated by different countries using different standards for their mapping work and using their own geodetic tables. Gulatee gave suggestions for effecting important changes in the existing standards of length and their calibration.

(2) Astronomical Observations of Latitude, Longitude and Azimuth

Dehradun Observatory is the primary meridian of longitude in India and is equipped with transit instruments and precision clocks. It has been participating in implementation of the International Longitude Scheme organized by the International Union of Astronomy. These important enterprises are designed among other things for precise determination of astronomical coordinates of a number of observatories by a study of variation of their coordinates. Extensive literature exists on the results of these observations.

In addition, at Dehradun Observatory, a variation of Latitude Programme by the Zenith telescope was carried out for three years (1930-33). The observations are recorded in Survey of India, Geodetic Report, Vol 7 (p. 21) and Vol 8 (p. 6). An analysis of these observations by Gulatee[2] enabled the diurnal and annual terms in the variation of latitude at Dehradun to be compared with the corresponding terms for other major observatories. The various complications in the problem were discussed by Gulatee in detail. The Dehradun observations showed no evidence of a relationship between latitude variation and moon's age.

(3) Deviation of the Vertical

Along with geodetic triangulation, the astronomical determinations of latitude, longitude and azimuth have an important role in geodetic work. The method of determining the deflection of the plumbline involves a combination of astronomical and triangulation observations. The earlier data regarding the deviation of the vertical were computed piecemeal at various times and lie scattered in a number of publications. In 1930, the International Union of Geodesy and Geophysics recommended that the results should be

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exhibited on International spheroid, so that investigators in other parts of the world could make use of them. By 1955, the number of stations was about 1250. These were brought to a uniform basis by Gulatee[3] for the first time by making several important improvements. A number of new important charts were included in the publication, such as 'Lines of equal deflections', which give a bird's eyeview of the variations in plumblines in India. In particular, they bring out vividly the steep gradients at the foot of the extensive Himalayan range, as also the unexpectedly large seaward deflections at some portions of the coast.

(4) Gravity

The geoid is a complicated figure and it is of great interest to derive a gravity formula appertaining to it. In India, some 3000 gravity stations had been observed till 1955 and were investigated and compiled for the first time by Gulatee[4] by making important changes to make them available for global studies. Among other things, the anomalies were computed on the International spheroid superseding the old 1901 Helmett's formula. They were also computed for the first time on several hypotheses. These anomalies have been shown on five charts to give a pictorial representation[4].

Gravity and arc measurement data as available currently show that a triaxial ellipsoid fits the geoid better, but the ellipticity still remains an open question, as the data are too scanty, the main desideratum being the values of gravity at sea and in the southern hemisphere. Gulatee[5,6] discussed the matter in detail and suggested plans for future action.

(5) Isostasy in India

Apart from their use in delineating the figure of the earth, gravity and geoidal observations the world over have shown that the larger features of visible topography are compensated in some form or the other. This is known as isostatic compensation. Several types of compensation have been suggested by different geodesists and elaborate tables have been prepared to compute their effects for various depths of compensation and thicknesses of the earth's crust. Data available in India were discussed by Gulatee[7,8] in detail with the help of elaborate calculations. These papers indicate that there are widespread areas which are not amenable to any form of isostasy. There is first a broad band of average breadth 350 miles with an elevation over 25 ft running across the whole breadth of peninsular India from Baluchistan to the Bay of Bengal. This is known as the 'Hidden Range'. Then there is a phenomenological rise in geoid in S Burma from Mandalay to Victoria Point, where it attains a height of over 100 ft. This has no parallel in the whole world and compared to it the 'Hidden Range' is comparatively insignificant. Yet another important finding has been that in certain areas in India, the subterranean mass-anomalies are greater than the topography to be compensated and that lack of isostatic equilibrium is much more pronounced in the neighbourhood of India than in India proper. India as a whole appears to be a region of deficient geoid and geoid appears to rise as we go east, west and north of the Indian frontiers.

The outer Himalayas are under-compensated and isostatic anomalies at most of the Himalayan stations are positive. A distribution of mass-anomalies expressed as a coating of normal crusted density on the reference spheroid has been determined from the isostatic anomalies in India[9]. It has been shown that the Gangetic plain is an area of underload, the deficiency being equivalent to a skin density of —500 to —2000 ft of rock condensed on the spheroid.

The results of observations on the Aravalli range in Central Rajputana having a moderate height of 2000 ft have been investigated[10]. Geoid there is more elevated than in the neighbouring regions. The gravity anomalies afford interesting features in seismically discussed areas and are discussed for Assam[11].

For a long time, the geodesists were puzzled by the gravity anomalies in S India, indicating large deficient mass underneath. This matter was discussed by Gulatee[12] in detail and it was shown that the earlier results were spurious and were due to an improbable depth of compensation of 113.7 km. With a regional type of compensation with a thickness of earth's crust of 15 km, the average anomaly on the geologically 'quiet' southern Precambrians becomes very small.

(6) Height of Mount Everest

Due to its unique position, Mount Everest has been the centre of controversies with regard to both its name and height. The older accepted height of 29002 ft was computed in an incomplete manner with a definitely wrong value of refraction and with no idea of the datum surface. The fixing of both the summit and the bottom of these lofty peaks observed from great distances is beset with several technical difficulties and it comes within the domain of higher geodesy involving a knowledge of advanced theory of refraction, plumbline deflections, gravity, datums of reference and so on. Our forebearers did not have the geodetic material at their disposal for ascertaining the general distortion of the plumbline as also of the mean sea level, produced by the Himalayan colossus; nor could they cope with the refraction which at their stations of observation, 100 miles or so away from Everest spheroid, could amount to as much as 1400 ft. A series of specialized observations were carried out in 1952-54 from mountains in Nepal not far from Mount Everest and a new height was determined[13]. The results obtained from these observations were unique in many ways. The newly discovered height of Mount Everest based on observations at 12 stations in the years 1952-54 is 29,028 ft. The close agreement with the older value is entirely fortuitous.

There was also doubt about the second highest mountain. The position was resolved by Gulatee[14] and he pointed out that the determination of heights of quite a number of peaks of the Himalayas is a task of the future.

(7) Terresterial Magnetism

Two of Gulatee's publications[15,16] gave the results of analysis conducted by him of the magnetic field data gathered from observations made by the Geodetic Branch of the Survey of India at 1400 field stations, 5 permanent magnetic observatories and 80 repeat stations.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986

Hari Narain

After obtaining the D Phil degree in Physics in 1950 from the Allahabad University under Prof. K S Krishnan, FRS, Hari Narain chose to switch over to the discipline of Geophysics and joined the University of Sydney, Australia, under a post-doctoral UNESCO fellowship. His doctoral thesis[1] on "Regional Gravity Traverses in Eastern and Central Australia" is still regarded as a classic work and is often referred to in regional gravity and lithospheric studies. The estimates of crustal thickness which he made then are surprisingly close to those obtained later using more sophisticated techniques.

Narain returned to India in July 1956 and joined the newly formed Oil & Natural Gas Commission (ONGC) in Dehradun. The geophysical surveys for petroleum carried out there and a number of technical reports submitted to ONGC, merited his appointment as the first Director of the Research and Training Institute of the ONGC now known as Keshav Deva Malaviya Institute of Petroleum Exploration. His concept of integrated basin studies and search for stratigraphic traps and pinch-outs in Cambay basin proved extremely valuable in search for oil in the ONGC.

Narain joined the Council of Scientific and Industrial Research as Director of the National Geophysical Research Institute (NGRI), Hyderabad, in 1964, and has brought both national and international recognition to the institute, over the years, through integrated studies in the various fields of Earth Sciences.

Narain has more than a hundred research papers and a large number of technical reports to his credit. He has been actively involved in seismological research at NGRI and has personally contributed to its present pre-eminent position in India and abroad. His work on seismic surface and body wave investigations and deep seismic sounding studies in the Himalayan-Pamir region has provided fuller understanding of, and deeper insight into, the crustal structure and tectonics of the region[2] and of the Indian sub-continent[3].

An estimate of crustal thickness of 65-70 km in the Himalayan and Tibet Plateau region, given for the first time from studies on dispersion of Rayleigh and Love waves, was postulated by him and Gupta[4]. This estimate has subsequently been confirmed by many research workers.

With Gupta and Rastogi, he contributed significantly to the study of the Koyna earthquakes and understanding of the phenomenon of reservoir-induced seismicity[5-9].

A new approach for the preparation of quantitative seismicity maps, deep seismic

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sounding profiles along different geological units in India and detailed body wave studies have been carried out by him and Kaila in several regions of the world to decipher crustal and upper mantle structures[10-19].

Integrated geological, geophysical and geochemical investigations of the Indian Shield and the Cuddapah basin by Narain and his coworkers have brought to light several distinctive features of Precambrian rocks of the Indian Peninsula[20-22].

His work on the Continental Margins of India highlighted some important structural features which include the extension of the Chagos-Maldive ridge covering the Kori High and the Bombay High[23,24].

With Kaila, Narain has given a new interpretation technique of refraction data for the solution of hidden layer problems of vital importance in oil exploration[25].

Narain's active involvement in aerogeophysical surveys for the first time in the country and their interpretation has helped in delineating several distinct intracrustal structures and mineral potentialities in Karnataka, Madhya Pradesh and Uttar Pradesh[26-29].

With R K Verma, Narain has studied and reviewed the Indian terrestrial heat flow and paleomagnetic data to correlate with continental movements[30,31].

In addition to his scientific studies and researches, Narain has been strongly advocating the need for an integrated approach to scientific exploration, exploitation and management of natural resources. In his presidential address titled "Geophysics—Its potentialities and need for mineral revolution in India" to the Section of Geology & Geophysics of the 59th Session of the Indian Science Congress (1972), Narain emphasized the need for large scale integrated surveys for mineral resources.

As President of the National Academy of Sciences, during its Golden Jubilee Session in October 1980, Narain gave an address on "Earth resources and an approach to rural development". At the 1979 session of the Academy, he talked of "Education, science and technology for development". He has delivered various commemoration and memorial lectures, including Prince Mukhramjah Lecture—1975, Prof S Bhagavantham 60th Birthday Commemoration Lecture—1976, A M N Ghosh Memorial Lecture—1973, Sir Thomas Henry Holland Memorial Lecture—1979, and Acharya Hem Chandra Das Gupta Centenary Lecture—1982.

As a Member of the National Committee on Science & Technology (1971-77), Narain took active part in the formulation of the Science & Technology Plan and through participation of scientists and technologists from the various institutions, such as GSI, ISM, NMDC, ONGC, CSIR, ICMR, FRI, etc., and the research institutions and universities, he brought out 12 volumes on Geodetic & Topographic Surveys; Mineral Resources; Oil & Natural Gas; Water Resources; Forests, Land, Soil, Wild Life and Environmental Sciences.

Narain was Surveyor General of India from 1972 to 1976 in addition to his position as Director, National Geophysical Research Institute. He also served as Vice-Chancellor of Banaras Hindu University for one term from 1978 to 1981. He is

UNDP Chief Project Coordinator since April 1983 based at NGRI, Hyderabad.

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P Koteswaram

Koteswaram joined the India Meteorological Department (IMD) in 1940 with a DSc degree in physics from the Madras University. His early work was on the use of Raman Effect in studies in molecular association and he published 13 papers. During his service in IMD, he worked at all the important meteorological centres and rose to the position of Director General of Observatories (DGO) in 1969 from which he retired in 1975. He worked as UNDP/WMO expert in Iran and as Professor of Meteorology at the Tehran University (1975-78). He was invited as a visiting scientist/professor by the Universities of Chicago, Hawaii and Miami (USA) and the National Centre of Atmospheric Research (NCAR) at Boulder (Colo). He was Honorary Professor of Meteorology and Oceanography, Andhra University, Waltair, Visakhapatnam during 1972-82.

Koteswaram was associated with the World Meteorological Organization (WMO), the International Civil Aviation Organization (ICAO) and U N Environmental Programme (UNEP) since their inception. He was elected member, Executive Committee of WMO in 1969 and Vice President 1971-75, the first Asian to occupy this position. His work in meteorology covered service, research and development and he initiated a number of new schemes in IMD during his tenure.

Research and Development Work

Koteswaram's researches in Indian meteorology were concerned mainly with Nor'westers, jet streams in the upper atmosphere, tropical cyclones and monsoons. In 1944, he classified Nor'wester thundersqualls over undivided Bengal into four types and verified them in 1957 after a meteorological radar was erected at Calcutta airport. In 1953, he and his collaborators found the existence of a subtropical westerly jet stream (STJ) over north India during the dry season (March-May). He was invited to visit the University of Chicago in 1955-56 and identified a tropical easterly jet (TEJ) over South Asia and N. Africa. In 1956, he analysed the mean surface structure of tropical cyclones over the Bay of Bengal. During a visit to the University of Hawaii in 1961, he found from an examination of satellite cloud imagery that a tropical cyclone over the Arabian sea had asymmetrical distribution of cloud cover at its inception. This was later identified as a distinct type by US meteorologists.

At the National Hurricane Research Laboratory (NMRL), Miami, USA, in 1964-66, Koteswaram found that the core of mature hurricanes over the Atlantic Ocean

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extended into the lower stratosphere and that the tropopause was elevated contrary to earlier views and the cyclone developed a cold top over the well known warm core.

Turning to the S W monsoon over India, Koteswaram postulated a meridional monsoon cell of a reverse Hadley type with its heat source over the Tibetan plateau and the adjoining Indian plains in summer and sink over the cooler equatorial Indian ocean and presented the hypothesis at a symposium on 'Monsoons of the world' held in New Delhi in 1958. The hypothesis was verified later by a number of workers in China, India and USSR. He investigated the formation and structure of monsoon depressions over the North Bay that intensify the SW monsoon from time to time and the influence of mid-tropospheric cyclones over the South Bay during 'breaks' or cessation of monsoon activity over the country. He and his collaborators studied the vagaries of monsoon rains over the country during more than 100 years and found a long period of oscillation of about 100 years over the west coast of India, and no significant trend over the rest of India.

Developmental Activities

In the early sixties, Koteswaram proposed and assisted the IMD in starting a Northern Hemisphere Exchange Centre (NHEC) and an Analysis Centre (NAAC) for global meteorological data at New Delhi, an Institute of Tropical Meteorology (ITM) at Pune with $ 800,000 aid from UN special fund and Extended Analysis and Prognostic Centres (EAPC) at the four international airports for providing service to long distance jet aviation. During his tenure as DGO, Koteswaram upgraded NHEC and NHAC as Regional Telecommunications Hub (RTH) and Regional Meteorological Centre (RMC), for the WMO, obtained a telecommunication computer for RTH as gift from the Government of the Netherlands to the Government of India and installed an IBM 360/44 scientific computer at NHAC (RMC). India became the first country in the tropics to experiment with computers and weather forecasting and establish fast telecommunication links via satellite for data exchanges with various countries. Koteswaram established directorates of telecommunications, satellite meteorology and hydrometeorology at IMD, Delhi, sections for stratospheric and mesospheric meteorology, air pollution and drought research at Pune and meteorological centres in the capitals of all the major states with flood meteorological offices for the flood-prone river catchments. He started a cyclone warning research centre (CWRC) at Madras and agricultural meteorology advisory services at the state capitals.

To issue reliable cyclone warnings to the public, Koteswaram set up, in the early seventies, a chain of cyclone warning radars (CWR) along the east and west coasts of India with satellite picture receivers to monitor cloud imagery transmitted by orbiting meteorological satellites of USA provided with automatic data transmission (APT) facility. He organized, during 1971-75, cyclone distress mitigation committees (CDMC) in the coastal states for disaster prevention.

International Monsoon Experiments

In 1961, Koteswaram collaborated with US scientists to design the meteorological component of the International Indian Ocean Expedition (IIOE) 1963-66 and assisted IMD in setting up an Internal Meteorological Centre (IMC) at Bombay with sorties made by instrumented aircraft of the Research Flight Facility (RFF) of USA in the Arabian Sea monsoon. IIOE provided considerable data in the upper air for the first time for R & D. In March 1970, Koteswaram proposed to WMO and the International Council of Scientific Unions (ICSU) at their joint meeting at Brussels, Belgium, that an international monsoon experiment (MONEX) be organized as part of the Global Atmospheric Research Programme (GARP). This proposal was accepted for implementation in 1978-79 along with the First GARP Global Experiment (FGGE). In the meantime, Koteswaram arranged an Indo-Soviet monsoon experiment (ISMEX) in 1973 and proposed another joint experiment 'Monsoon-77' for 1977. MONEX conducted in 1978-79 to investigate the winter and summer monsoons provided a wealth of observational data over the Asian monsoon area using sophisticated equipment ranging from research ships and aircraft to geostationary satellites. These data are being utilized for R & D by participating scientists in India, USA, USSR, etc. to understand the nature and vagaries of the monsoon.

For his contributions in Indian meteorology, Koteswaram was awarded the honorary DSc degree of the Andhra University in 1972, was elected FNA in 1974 and Fellow of the Indian Academy of Sciences and A P Academy of Sciences in 1975. The President of India conferred 'Padma Bhushan' on him in 1975.

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A Mani

My earliest work, carried out at the Indian Institute of Science, Bangalore, was on the fluorescence, absorption and scattering of light in ruby and diamond. A detailed study of the fluorescence and absorption spectra of diamonds of widely different intensities and colours of luminescence showed the existence of a clear relationship between the two spectra, both in their general character and their intensities. The frequency differences between the principal electronic lines and the lattice lines were found to represent the vibration frequencies of the diamond lattice.

My later work in the India Meteorological Department at Pune was in atmospheric physics—cloud and rain physics, atmospheric electricity, atmospheric ozone, radiation—and instrumentation. Radar studies of thunderstorms and of precipitation processes in clouds provided quantitative information on the rates of growth and dissipation of thunderclouds, the nature of the "melting band" and the initial release of precipitation in clouds.

In addition to the design and development of a number of instruments for routine meteorological measurements, instruments for measuring the various short-wave and long-wave components of the radiation balance of the earth and the atmosphere were developed during the sixties. A network of radiation stations for regular measurements of direct, global and diffuse solar radiation, long-wave and net radiation and the albedo were established and a radiation climatology for India and its neighbourhood evolved. Aircraft measurements of the upward and downward short-wave radiation fluxes and balloon measurements of the vertical distribution of the infrared radiative fluxes in the atmosphere were also carried out at the same time.

The study of the depletion of the downward beam of radiation in selected spectral bands has provided valuable information on the dust content of the troposphere and stratosphere and provided data on an aerosol climatology for India. Normal concepts regarding atmospheric turbidity parameters have to be radically altered to fit in with Indian observations especially during the premonsoon months.

Atmospheric ozone is a very important parameter in the study of the fundamental physical processes affecting the energetics and motions of the atmosphere. An electrochemical ozonesonde to measure the vertical distribution of ozone in the atmosphere was developed at Pune and is now flown from a number of stations in India. Ozone exists in relatively small concentrations throughout the troposphere, the concentration increasing

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markedly with height in the lower stratosphere, reaching a maximum at 25-28 km. Studies of latitudinal and seasonal variations of ozone have shown that information on the formation and transport of this atmospheric tracer, a quasi-conservative property below 20-25 km, is of great importance in understanding the physics and dynamics of the atmosphere.

Measurements of atmospheric electricity, the electrical field, the electrical conductivity of the air and the air-earth current, are also important, providing as they do a valuable index of the time variations of global electrical activity. Measurements of these parameters, both at the earth's surface and in the free atmosphere, using electrographs and balloon-borne electrosondes, have provided information on their seasonal variations and further evidence of the presence of dust layers in the stratosphere.

My most recent work at Bangalore relates to studies of solar and wind energy resources and the preparation of climatological data handbooks for India. Using both measured data and theoretical models, radiation data of importance to solar energy users have been compiled/computed and published in two volumes, for nearly 150 stations in the country, and wind data at 400 stations for the design and use of wind energy conversion systems in the third volume.

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S S Merh

Merh has specialized in structural geology. He wrote his PhD thesis on Scottish Highlands at Imperial College of Science & Technology, London. After his return to India in 1960, he actively worked in Kumaon and Nepal Himalaya for almost 20 years.

Merh is known for his original contributions in the field of structural and metamorphic geology. He has worked extensively in the Himalayas of Kumaon and Central Nepal and is one of the noted workers in Himalayan geology. He has also contributed substantially to geological studies in the Precambrians of Gujarat. Forty students have successfully completed their doctoral studies on various topics pertaining to Himalaya and Gujarat. He has been closely associated with the Wadia Institute of Himalayan Geology, Dehradun, since its inception. Currently, he is the President of that Institute and the Chairman of its Governing Body.

Merh has diverse research interests, and in recent years he has been devoting attention mostly to Quaternary Geology. He has formulated a multidisciplinary research programme on Quaternary Geology relevant to India. As a quaternary geologist, he has worked on the Gujarat and Saurashtra Coastline, Rann of Kutch and Miliolite rocks of Saurashtra.

The Department of Geology at Baroda, which was started by Merh, has in the course of the last 25 years, developed into a reputed centre of postgraduate teaching and research in the country. He is now busy developing this department as an all-India centre for Quaternary Research.

Merh presided over the Geology and Geography Section of the 67th Indian Science Congress held at Jadavpur in 1980, and was also the General President of the Indian Geological Congress for the period 1980-82.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

R C Misra

Misra's main theme of research was initially related to the Bundelkhand Massif, later extended to the Vindhyan syneclise and beyond into the Lesser Himalaya. This, as is now known, marks the extension of the Vindhyan sediments as well as Bundelkhand beneath the Ganga basin and further northwards into the Himalayan Tectonic Zone.

His contributions to the geology of Vindhyanchal, Bundelkhand and the Himalaya have been well recognized. His discovery of minerals pyrophyllite and diaspore in Bundelkhand, formerly unknown in India, has helped in the development of refractories industry. The discoveries of volcanic bombs in the agglomeratic slates of Kashmir and Salt-pseudomorph shales in the Vindhyans are notable contributions. The wide range of topics covered reflect the rich vistas exposed by him for research and enquiry through exciting avenues in earth sciences. As such, a large number of his students have made valuable contributions under his guidance in various facets of geology. From the ancient granitic rocks of Bundelkhand to the river and dune sands, a rich panorama of fruitful research emerged; it was not a far cry.

The Bundelkhand granites, described by earlier workers as monotonous and without variations in mineral composition and texture, received the attention of Misra in the forties. He was able to demonstrate convincingly that the Bundelkhand granites showed considerable variation and there were a number of episodes of large scale granitic activity. As a result of mixing of granitic fluids and pre-existing rocks, mostly of schistose nature, the hybrid rocks developed.

It was also demonstrated that the agmatites constitute a stage in the process of granitization. The granite and associated rocks were correlated with the Peninsular Gneisses of Middle Dharwarian Age. Associated with Quartz Reefs, rich deposits of pyrophyllite and diaspore, hitherto unknown in India, were discovered. These minerals are a potential source of raw materials for refractories, and were known at that time occurring only in North Carolina, USA and Japan.

The contributions in the field of economic geology and applied geology are also noteworthy. In a paper, several suggestions were made for the development of mineral industries as a result of power generation in Rihand, mainly cement, aluminium and ceramics. These are now in operation in the district of Mirzapur, UP. Glass sands—the raw material for glass industry—were also studied and ground waters received due attention.

Pioneering sedimentological studies of dune sands, river sands and Siwalik

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sediments laid the foundation for such studies. In subsequent years, the Lucknow school has been recognized as a notable centre for studies in sedimentology. Vindhyans and a number of sedimentary formations in the Himalaya received special attention.

With the initial studies relating to the occurrence of early life in the Precambrian rocks of India, considerable headway has been made in this fascinating area. What was supposed to be a futile search for records for life in ancient rocks gave rise to evidences of prolific life now preserved in the form of microbiota, mainly algae, bacteria and fungi. Misra's work in this regard has been recognized internationally.

Work relating to Himalayan Geology, with special reference to Kumaun Himalaya, has been adjudged as of high rank and the contributions made by Misra, his colleagues and students on various aspects, such as structural, tectonics, petrochemistry, bio-stratigraphy, sedimentology, economic geology, etc., are considered as work of reference. The magnesite deposits are being worked out economically.

Presently, Misra is engaged in the vital study of environmental problems, with special reference to the effects of mining of minerals and rocks in the Himalaya. With this end in view, the effects of mining in the district of Dehradun have been studied in detail. It has been found that there is a marked degradation of land, sometimes leading to landslides, particularly on account of limestone mining. The dust and debris have disturbed the drainage system. Blasting also leads to noise pollution. Limestone kilns situated within the town add harmful gases to the atmosphere. Deforestation is very pronounced.

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Asoke Mookherjee

Earth scientists are increasingly converging to the view that there is a method in the madness of Nature in endowing certain sectors of the earth's crust with rich mineral resources—to the exclusion of other areas. Such 'selectivity' in ore localization is primarily the result of a very complex interaction among geotectonic and geochemical parameters. Therefore, to find the reason why ore deposits are where-they-are, it is necessary to identify the special geotectonic and geochemical features endemic to known ore deposits—and then to search for ores in virgin areas where such features obtain. This has been the central theme of research activities of Mookherjee over the last three decades.

Research work on Zawar[1-3] constitutes the earliest attempt in this country to reconstruct the physico-chemical environment of mineralization quantitatively in terms of $P.$, $T.$, a_{S_2} and other intensive parameters. It was demonstrated that, contrary to the prevailing notion, metal-zoning in ore bodies is not a simple function of temperature alone. Another intriguing 'live' problem during the fifties was: how does the ore-forming fluid perform the seemingly impossible task of holding both metal ions and sulphide ions together, avoiding precipitation? Complexing of metal ions was just being considered as a possible answer; a vital clue was furnished by demonstrating through radioactive tracer technique that partitioning of Cd, between a solution and crystals of sphalerite (ZnS) precipitating from the solution, is markedly changed when the solution is chloride-free and chloride-rich[1], implying thereby a significant difference in stabilities of zinc and cadmium complexes. The work has been widely acclaimed and referred to in standard text and reference books (Helgeson; Vlasov; Barnes).

Most ore deposits in ancient shield areas (like those in the Indian, Canadian and Scandinavian shields) have a long, billion-year post-depositional history. Post-ore geologic events like deformation metamorphism and igneous activities had left their marks on such deposits, often to blur their pristine characteristics almost beyond recognition. Surprisingly, recognition of the imprints of later events on ore deposits—unlike the case of metamorphism and deformation of common rocks—had been slow. The reason was partly historical—earth scientists having been swayed by the Lindgrenian conceptual model that most ore deposits are epigenetic and young—and partly phenomenological—the ore minerals in general being 'umquenchable', that is, they do not 'freeze' the post-depositional thermal and tectonic events as effectively as the common rocks do.

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Some of the earliest work on metamorphism of sulphide ores stands to the credit of Mookherjee[4–7]. Further, regional metamorphism, in addition to transforming rocks, often generates geologic fluid on a regional scale; such fluid under special situations may become a potential mineralizer. Mookherjee's contributions on modifying, dispersive and 'creative' roles of metamorphism in ore-generation prompted the Series Editor of '*The Handbook of Stratabound and Stratiform Ores*' to invite the contribution on '*Ores and Metamorphism*' (Vol. 4, Chapter 5).

Work along these lines generated some new ideas on regional metallogeny of the Indian shield; it also involved investigations in minute details that led to the discovery of one new and several extremely rare sulphide/sulphosalt minerals from Indian deposits[8–12].

The earliest attempt[13] in this country, in applying trace element geochemistry to solve problems of ore genesis, has been continued[14] with increasing sophistication of analytical and theoretical approach.

Future research programme aims at two directions: characterization—through thermodynamic and analytical-formulation approach[15]—of the progressively-changing physicochemical variables that influence hydrothermal mineralizing systems; and recognition of possible changes in *composition* and *style* of mineralization through space and (geologic) time. Inasmuch as formation of ore deposits constitutes an integral component of the evolutionary history of the crust as a whole, a parallelism in the evolutionary trends is expected to exist. Such pattern recognition would be of great help in locating ore deposits in virgin areas.

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K Naha

Naha carried out research work in three broad fields of geology: (1) Structural geology; (2) metamorphism in relation to structure and stratigraphy; and (3) different aspect of Precambrian geology.

(1) Structural Geology

(i) Deformation lamellae in quartz have been reported from metamorphic rocks for a long time, but their orientation in relation to strain and their time relation with deformation episodes were subjects of speculation. From structural, petrographic and petrofabric studies, it was demonstrated that deformation lamellae in quartz develop at a late stage of deformation parallel to the conjugate planes of maximum shearing strain. This was confirmed subsequently through experimental deformation studies by Griggs and his associates at the University of California at Los Angeles, USA.

(ii) The properties of a new type of fold—reclined fold—and the methods of identifying it in the field have been elucidated from studies in the Precambrian terrane of east Singhbhum. During the last three decades, these folds have been found to be very common in orogenic belts.

(iii) Methods of recognizing overthrusts in metamorphic terranes involved in polymetamorphism and multiple deformations have been worked out during studies in the Simla Himalayas.

(iv) Methods of elucidating large-scale architecture of migmatites, by tracing relict metasedimentary bands in folded attitude and by analyzing them in association with minor deformational structures, have been developed. These methods have been successfully utilized in tracing the detailed history of superposed deformations in the Banded Gneissic Complex of Rajasthan.

(v) Methods of identifying angular unconformity in metamorphic terranes, with groups of rocks on either side of the unconformity involved in superposed folding, have been developed. These methods have been utilized in delineating the angular unconformity between the Aravalli and the Delhi Group in Rajasthan.

(vi) A critical analysis of the concept of 'orogenic trends' and its importance in the correlation of the metamorphosed Precambrian rocks of Peninsular India has shown that this concept needs significant revision. Only trends of regional fold axes may be of help for correlation purposes, particularly in terranes not involved in multiple folding.

(vii) The geometry and mechanism of folding, in general, and superposed folding, in particular, have been worked out, and the principles fruitfully applied to unravel

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the structural history of the Precambrian rocks of Rajasthan and of the Jutogh-Chail rocks of the Simla Himalayas. Methods of recognizing coaxial folding prior to non-coaxial deformation have been developed, and the nature of variation due to superposition of upright folding of varying intensity on isoclinal folds of diverse orientation has been clarified. In the Precambrian terrane of central Rajasthan, in particular, the shapes of folds of different generations, the behaviour of early lineations involved in later folding, and the orientation of late-stage conjugate folds and kink bands, have been utilized in deciphering the style, sequence and extent of strain in the rocks, and in calculating the extent of buckle shortening and homogeneous strain that the rocks have undergone.

(2) Metamorphism in Relation to Structure and Stratigraphy

The variation in regional metamorphism with stratigraphic succession and fold geometry in space, and with movement phases in time, has been studied in the Precambrian terrane of east Singhbhum and in the Simla Himalayas.

(i) Structural data from the scale of map to hand specimen, and metamorphic textures in thin section have been brought to bear on the question of time-and-space relationship of progressive regional metamorphism in Singhbhum. It has been shown that in the Ghatsila area in Singhbhum, the progressive regional metamorphism is broadly coeval with the folding movement, with the isograd surfaces accordant with the fold geometry. It has been established that the progressive metamorphic series is progressive not only in space but also in time. The progressive metamorphic suite was affected by dislocation metamorphism along a thrust zone, resulting in retrogression.

(ii) Structural, stratigraphic and metamorphic studies in the Simla Himalayas have established that the metamorphic rocks of the Jutogh Series, structurally overlying the less metamorphosed Chail rocks along a thrust contact, have been involved in three episodes of deformation interspersed with metamorphism in two phases. The first metamorphism ranging from albite-epidote amphibolite facies to amphibolite facies, is late- to post-kinematic with reference to the first deformation which resulted in large-scale recumbent/reclined folds. The second metamorphism, syn- to post-tectonic with reference to the second deformation during which the Jutogh thrust formed, is generally in the green schist facies. The very low grade rocks of the Chail Series surrounding the rocks of the Jutogh Series show a partly independent trend of metamorphism and deformation.

(3) Precambrian Geology

(i) Studies on stratigraphy, sedimentation, structure and metamorphism of the Precambrian rocks around Ghatsila in eastern Singhbhum have led to an integrated geological history of this metamorphic belt. A geosynclinal trough, bordered to the south by a granitic land mass and to the north by a volcanic island arc, was formed at the first stage. A thick suite of flysch sediments, derived mainly from the southern land mass, was deposited in this trough. These sediments were involved in flexural slip folding with subvertical axial planes and with gentle plunge toward ESE or WNW in the first stage of deformation. Locally, the axial planes were coaxially folded with the main folds. Progressive regional metamorphism from the chlorite to the kyanite grade affected the rocks contemporaneously with folding, with the higher and lower grade rocks occurring in the deeper and shallower tectonic and stratigraphic levels respectively. A dislocation metamorphism was superimposed on this progressive metamorphic suite, owing to large-scale thrusting in the southern part of the area. Linear structures of diverse types and orientations were formed in different stages of folding, unrestricted transport during thrusting and impeded transport in the final phase of thrusting.

(ii) Work on some of the oldest rocks in the Rajasthan Precambrians has led to a revision of the stratigraphy and structure of the Aravalli-Raialo rocks and the Banded Gneissic Complex of the type area in central Rajasthan. The study has demonstrated the presence of structures of three generations in large scale, with EW-trending isoclinal folds of varying axial planes (because of coaxial refolding) affected by NNE-trending upright folds of varying tightness. On these structures, conjugate folds and kink bands have developed locally by vertical compression, followed by NE-SW horizontal squeezing. The Aravalli-Raialo rocks form a conformable sequence older than some of the supposedly basement gneisses, the latter representing the migmatized portions of the metasedimentary groups. Evidence of granitic and gneissic rocks of more than one generation in the Early Precambrian of central Rajasthan, with mobilization of the basement during the first recognizable deformation in the Aravalli rocks, has been adduced. These findings have been confirmed by radiometric dating of carefully selected samples in different laboratories.

(iii) Folds of three generations in small and large scales have been traced in the Bababudan Hill Ranges of Karnataka. The isoclinal first folds on westerly plunging axes were overprinted by near-coaxial, upright open folding, which caused a swing in strike not only of the bedding planes but of the axial planes of the first folds also. These refolded folds were affected in the final phase by upright, open folding on N- to NNE-striking axial planes, causing plunge culminations and depressions of the early fold axes and different interference patterns. Reconnaissance studies have shown that this structural sequence is present in other parts of Karnataka also.

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S M Naqvi

Naqvi has been working on Precambrian rocks of India (Dharwar Craton) since 1965. During this period, he has made outstanding contributions in the field of Precambrian geology and geochemistry, particularly regarding the early stages of evolution of continental crust and lithosphere and development and exploration of base metal deposits in Karnataka. His work has been recognized internationally and referred to and cited widely. He has established a highly sophisticated geochemical laboratory at the National Geophysical Research Institute (NGRI), Hyderabad, which is working as a national facility.

He has provided field and laboratory evidence for the existence of a primordial simatic crust made up mostly of basic-ultrabasic lavas, and its subsequent transformation to present-day sial during early Archaean to middle proterozoic through a combination of processes mainly resulting due to interaction of the lithosphere and the hydrosphere. Along with Dr Hari Narain, Dr Divakara Rao and other members of the geochemistry research group of NGRI, he has shown that these processes of crustal evolution have been unidirectional and the events that occurred in the early Precambrian have not been repeated in space and time. This major and significant conclusion was drawn on the basis of the following observations. Macro- and microspinifex textures have been recognized in the ultramafic rocks at various places in the early greenstone belts. Similarly, evidences have been obtained for the possibility of formation of the anorthositic lavas. These highly calcic anorthosites from Holenarsipur greenstone belt are comparable with lunar anorthosites. This high Ca-Mg volcanic activity of basic-ultrabasic lavas is not found in the younger sequence of the craton.

Naqvi also noticed secular variation in the distribution of elements during 4-2.1 Ga era and proposed 2.1 Ga as the major discontinuity in the early history of the evolution of the earth. Lithostratigraphic division of the Dharwar Supracrustal and Peninsular gneisses into five successive polymetamorphic interfingering groups has also been suggested by him.

Naqvi has demonstrated that the early Archaean sediments are mainly chemogenic and have unusual abundances of Ni, Cr, Mg, Fe, Al and REE patterns, indicating that the after-effects of extra-terrestrial bombardment of the earth analogous to moon during its early history have swept into the early Archaean sedimentary basins. The negative and positive anomalies found in the Precambrian sediments are independent of time-space control. His studies on the

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pebbles of Dharwar conglomerate indicated that the K-rich granites were seldom present in the crust before 2.6 Ga. These granites were emplaced between 2.6 and 2.0 Ga. And they form a garland round the Karnataka Nuclei. An intense K-metasomatic event occurring at 3.0 Ga has also been recorded by Naqvi and coworkers.

His structural geology work with Prof. K Naha and Dr R Srinivasan showed that Dharwar supracrustals and Peninsular gneisses are characterized by a 3-phase deformational structure history, but deformational signatures of still older events are preserved as bent lineations in the folded pebbles of the conglomerate and a few enclaves in 3.0-3.4 Ga old gneisses. He has envisaged that the stress directions have remained E-W during a long period of early Precambrian. Chitradurga schist belt has been produced by such E-W compression and movement. He has proposed that this belt may be an Archaean Suture. He has also recognized four different types of greywackes in the Chitradurga schist belt from N-S; their geochemistry indicates a deeper oceanic environment of formation.

He has cited numerous evidences from India to suggest that after 4.0 Ga, most of the geological processes have been controlled by hydrosphere and it is the presence of hydrosphere which has made earth unique and so different from other planets. Based on these and other studies, Naqvi, along with Dr B P Radhakrishna, has proposed that the Precambrian crustal landmass south of Narmada Son lineament constitutes a single landmass; he named it as Dharwar Singhbhum protocontinent. This protocontinent constitutes three nuclei, namely Karnataka Nuclei (KN), Jeypore-Bastar Nuclei (JBN), Singhbhum Nuclei (SN) and Early Proterozoic Mobile Belt (EPMB). The nuclei and their surrounding EPMB is enclosed by the Middle Proterozoic Mobile Belt (MPMB) of Eastern Ghat and Satpura region. Early Proterozoic Mobile Belt (EPMB) event involved sedimentation formation of amphibolite-granulite facies rocks and emplacement of K-granites in the north and formation of the charnockite and other granulite facies rocks in the south. It has been postulated that the Middle Proterozoic Mobile Belts (EPMB), namely Eastern Ghat belt, Satpura belt and Delhi belt, were produced by collision tectonics between the various protocontinental masses of Gondwanaland. Most of the continental crust of India was formed prior to 2.6 Ga. However, it has been remobilized at least twice in the 2.6-1.5 Ga span. Karnataka, Jeypore-Bastar and Singhbhum Nuclei, characterized by BIFs and tonalitic gneisses, are the relics of the older crust which has not been affected by later activities. Their model envisages that older schist belts were developed in shallow water basins on a simatic crust. The platformal components of the younger greenstone belts, on the other hand, were laid down in rifted basins on a sialic basement. Crustal deformation and thickening of the crust gave rise to the EPMB. At 2.0-1.5 Ga ago, another intensive mobile belt event occurred in which subduction and flexure at the eastern and northern margins of the Dharwar-Singhbhum protocontinent gave rise to Proterozoic sedimentary basins, rift valleys and igneous and metamorphic suites. Naqvi has proposed that plate tectonic regimes had clearly set in by 2.0 Ga ago and the middle Proterozoic progeny shows evidence of modern style collision tectonics.

Naqvi has been recipient of the Gold Medal of the Geological Society of India and the Shanti Swarup Bhatnagar Award. He has written about 92 research papers, edited four books and has also written a book entitled *Precambrian Geology of India* (Oxford University Press, New York). He has organized two international seminars and coordinated an Indo-US project on Precambrian of South India.

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I C Pande

After obtaining his MSc degree from Banaras Hindu University in 1941, Pande has been engaged in deciphering the geology of Himalaya. His field of investigation has been more or less confined to Kumaon-Garhwal and Simla Himalaya. His paper[1] reporting the results of investigations in Kumaon Himalaya, dealt with 'Ramgarh thrust' and occurrence of migmatite for the first time. The occurrence of Ramgarh thrust has also been supported by Prof. K S Valdiya (1981), who extended the thrust further towards north and southeast side.

Pande worked on the geology of Donegal area, Ireland (1952-54), under Prof H H Read, FRS and put forward the theory of stratigraphic continuity in rafts preserved within the Donegal granite. This has been an important contribution from him[2].

After training in UK under Prof H H Read, FRS, Pande continued his investigation on the Himalayan geology. He redefined and designated the Ramgarh Porphyrics (Heim & Ganssar 1939) as 'migmatites'[3]. Encouraged by his teachers (Late Prof Rajnath, FNA and Prof K P Rode), he wrote and published two papers[4,5] based on field and laboratory data. The hypothesis of migmatization for the origin of Himalayan gneisses was expounded by him for the first time[4].

This hypothesis of migmatization of the "Himalayan Metasedimentaries" (Precambrian or Early Palaeozoic) has been further confirmed in a number of papers published by him individually and jointly[3,5–9].

Pande has been the first investigator to advocate that in Himalaya the "main phase" of metamorphism occurred during the Tertiary time as a sequel to the Alpine-Himalayan Orogeny[3,10]. Earlier, the crystalline rocks of the Himalaya were thought to be a product of Pre-Himalayan Orogeny (Pre-Cambrian). Pande also advocated for the first time that regional metamorphism and migmatization are part and parcel of Tertiary orogenesis[4,5]. According to him, metamorphism had been polyphased and migmatization represents the second event in the metamorphic history of the Himalayan rocks. He advocated Litpar-Lit metasomatic replacement of the country rock to form migmatite (gneisses)[4–6].

His laboratory and field studies on Himalayan metamorphite show that the Himalayan rocks were repeatedly deformed. This conclusion is based on the study of meso- and microstructure, texture and mineral relations under the microscope[11–16].

Pande, on the basis of his vast experience of the Himalayan geology, put

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forward his third hypothesis of polygeosynclinal evolution of the Himalaya[7,16,17]. Till then, it had been a common understanding and universally accepted theory that the Himalaya had originated from a single sedimentary basin, the Tethysis (Suess, 1904; Wadia, 1955; Krishnaswamy and Swaminathan, 1965 and others). These authors were of the view that the Tethyan geosyncline gave rise to Himalaya during Alpine-Himalayan Orogeny. However, Pande differed with the above theory and proposed the existence of twin geosynclines[9]. The northern eugeosyncline and southern meogeosyncline delineated by Central Crystalline axis[17]. This hypothesis was supported and corroborated by G Fuchs in 1967. Both Pande and Fuchs independently came to same conclusion regarding this origin of the Himalayan mountain system. This view is now being accepted by many geoscientists working on the geology of the Himalaya.

In recent years, Pande has advanced the view that the formation of fold and parallel belts of mountains of the Central Asia took place as a result of activation of primary 'Deep-seated Faults' (Narbe) varying in time and space from North to South[18]. This new concept is being further developed by him[19].

At present, Pande is working on the geology of the Lesser Himalayan Zone. So far, he has published, individually or jointly, more than 100 research papers and about 25 scholars have obtained PhD degree under his guidance. Under a DST (Govt of India) scheme he is also writing a monograph on the "Tectonic and metamorphic history of Lesser Garhwal-Kumaon Himalaya with reference to mineralization along deep fracture".

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C S Pichamuthu

Sedimentary Origin of Some Dharwar Rocks

From 1910 onwards, under the influence of Dr W F Smeeth and Prof P Sampat Iyengar, all the rock formations of the Dharwars were considered to be of igneous origin. The conglomerates were not normal sedimentary rocks but autoclastic in origin, i.e., crush conglomerates formed by pressure; the quartzites were supposed to represent crushed vein quartz, felsite or quartz porphyry; the limestones were considered to be either highly calcified portions of mafic rocks or metasomatic replacements of silicic Champion gneisses; the ferruginous quartzites were believed to be derived by the alteration of amphibolites; and the kyanite-staurolite schists, sillimanite-cordierite gneisses, and similar rocks were looked upon as having been formed by the contact metamorphism of mafic igneous rocks.

It was in such a setting that, for the first time in 1932, typical current bedding was recognized in the quartzites occurring in some parts of the Bababudan area in the Shimoga schist belt. Apart from the discovery of ripple marks and current bedding in the quartzites (1935), graded bedding was observed in the grits associated with the Kaldurga conglomerates (1935). Those grits were of two types, one characterized by the abundance of chlorite which was a greywacke and the other more gritty and feldspathic, which was an arkose (1936).

Infraformational folding and brecciation were noticed in the banded ferruginous quartzites which are ascribable to the effects of submarine earthquakes during the time of deposition (1935). These rocks, which are well developed in Karnataka, were considered to have been formed by the decomposition and reconstruction of bababudanite and cummingtonite schists and other amphibole-bearing rocks of igneous origin. It was noticed in 1932 that fresh acicular crystals of bababudanite were developed right across the banding of the iron formations and so were formed later. They could not, therefore, have been the original minerals by the breakdown of which the banded iron formations could have originated (1935). The prevailing rocks in the Bababudan area are mafic flows and schists by the disintegration and decomposition of which the necessary iron and silica could have been separated and later transported into sedimentary basins where they were deposited as banded iron formations (1974). The precipitation of iron and silica could have been caused by the influence of algae or bacteria. The discovery, therefore, of algae in the Precambrian cherts associated with the iron formations near Dodguni (1945)

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suggests that organisms could have been a contributing factor for the origin of these rocks.

The recognition of such sedimentary features led to the formulation of cycles of sequences in certain Dharwar sediments. The discovery of sedimentary features in the Dharwar rocks was epoch-making in that it marked a turning point in the history of research on the Precambrian of south India. The then prevailing all-igneous view had to be given up, since it was demonstrated conclusively that certain members of the Dharwar sequence were of undoubted sedimentry origin.

Mafic Volcanic Rocks

Investigations on the volcanic components of the Dharwar Group commenced as early as 1927 with a study of the mafic intrusives and flows in the Chitradurga and Shimoga schist belts. The Lingadahalli trap which was considered by earlier workers as intrusive was shown to be volcanic flows containing amygdales.

Spilitic rocks were recognized for the first time in the Shimoga schist belt of Karnataka (1935). Pillow structures were reported first from the Chitradurga schist belt (1938) and later from all the Dharwar areas in Karnataka (1957). Typical variolitic structures were also found in the volcanic rocks near Chitradurga (1952). Tuffs and agglomerates were associated in many places with Dharwar sediments.

Gneisses and Granites

The composite and migmatitic nature of the Peninsular gneiss was recognized as early as 1932. Attention was drawn to the fact that the Gneiss was a complex and not a stratigraphic unit and also that this polymetamorphic complex was not the primitive sialic crust.

The Closepet granite presents great variations from coarsely porphyritic pink and grey rocks to granitic and gneissic type. This band of granite has a pronounced Dharwarian trend with the Sandur schist belt in the north It contains remnant resister rocks like quartzites, banded ferruginous quartzites, and amphibolites, which suggest that an original schist belt here has granitised (1950). Diapir-like plugs of granite are found at intervals along this trend.

Progressive Metamorphism and Charnockitization

In the southern part of Karnataka, it was possible to recognize zones characteristic of greenschist facies, epidote-amphibolite facies, and granulite facies. The schist bands run roughly north to south and the isograds transect them. The progressive increase in the grade of metamorphism can be recognized in the schists, the gneisses, the limestones, and the banded iron formations. The rocks of the schist-gneiss complex have undergone these progressive changes, until finally charnockites and associated high grade metamorphic rocks developed in the granulite zone.

A comprehensive account was given in 1953 of the charnockites of southern India. Two types of charnockite were recognized: an older variety which is gneissic or granulitic formed by regional metamorphism of pre-existing schists and gneisses, and a younger one which is coarse-grained and granitic, formed by anatexis. A statistical study based on the occurrence of clouded plagioclase in about 500 mafic dykes of different ages and petrography showed that the clouded dykes were confined mainly to the charnockite region. These dykes transect the earlier gneisses and charnockites, and the thermal metamorphism during the formation of the second type of charnockite produced clouding in the plagioclases of these dykes. This indicates that there were two separate periods of metamorphism during the earlier of which the gneissic and granulitic types of charnockite originated and during the later, the coarse granitic types.

The remarkable resemblances between the charnockites of India and the Antarctica were pointed out in a comparative study.

No direct evidence was found for considering the charnockite region as constituting the lowest parts of the crust in south India. Charnockites have been formed during different periods of metamorphism with a wide spacing of ages. There are charnockites in Kerala, Tamil Nadu, Andhra Pradesh and Karnataka, which are definitely intrusive into gneisses. Evidence was found (1960, 1961) for the transformation of some Peninsular gneisses into charnockites. This started a new line of thinking and was followed by several workers adopting the transformist view of the origin of charnockites as against the classical magmatic origin.

Tectonics

Structural studies of the Dharwars commenced in 1937, when for the first time in south India current bedding in quartzites was used to indicate the order of succession. By applying this technique, the Dodguni plunging fold was found to be a true anticline.

By using a prominent banded ferruginous quartzite-manganese-limestone formation as marker (1951), it was shown that the Dharwars in southern Karnataka were folded into an anticlinorium with many minor anticlines and synclines which were uniformly plunging NNW. It was possible to connect the Shimoga and Chitradurga schist belts into an unified structure.

The structure of the Bababudans was interpreted in 1961 as caused by refolding of a plunging syncline which closed eastward. The impact of the Eastern Ghats strike on that of the Dharwars is demarcated by the occurrence of a zone of mylonites and crushed gneisses; the general trend of the Dharwars which is NNW-SSE in the west, and N-S in the centre, changes southwards first to SW and finally to almost W.

Stratigraphy

The relative age of the Dharwar schists and Peninsular gneiss was discussed in 1947 in the presidential address to the Geology Section of the Indian Science Congress. Because some of the oldest volcanic rocks contain pillow structures indicating their submarine origin and since associated with these ancient rocks there are certain earliest-formed sediments such as thin bands of siliceous schist, it was concluded that the lower Dharwars could not be the oldest rocks.

The problem of the basement was reviewed in 1970. The unmistakable evidences of intrusion of gneisses as well as the range of radiometric ages indicated that some of the gneisses were younger than the schists. The conclusion was arrived at that the Peninsular gneiss is not a stratigraphic formation but a polymetamorphic complex comprising many units, some of which are younger than the Dharwar schists, while some may be older, probably representing part of the basement on which the Dharwars rest.

An evaluation was made (1963) of the position of the "Dharwar system" in the Indian Precambrian. The far-flung outcrops of "Dharwars" in Peninsular India, though lithologically somewhat similar, were of different ages and could not be clubbed together as one stratigraphical unit. Hence, the term "Dharwar" should be used only for the type occurrence in south Karnataka.

The arbitrary fixation of the upper limit of the Archaean at 2500-2600 my leads to irreconcilable anomalies, since such a limit cuts across the known ages of all the three prominent constituents—the Dharwar schists, the Peninsular gneisses, and the charnockites.

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P R Pisharoty

Meteorology and Remote Sensing

The scientific contributions of Pisharoty can be broadly divided into two categories: (1) In the field of meteorology, mostly carried out under the umbrella of the India Meteorological Department, and (2) in the field of remote sensing of earth resources from aircraft and space-craft platforms, carried out under the umbrella of the Physical Research Laboratory, Ahmedabad, and the Indian Space Research Organization.

India Meteorological Department being an "established" department, Pisharoty, trained in research work by Prof C V Raman, had not much difficulty in carrying out investigations, except that during most of his service he was posted on the operational duties of weather forecasting at Pune and Delhi. However, in remote sensing of earth resources, he had to start from scratch in India. In fact, he was responsible for introducing this multidisciplinary technology in India. First he had to "sell" the idea to the different scientific organizations in India through a series of lectures and also by carrying out field experiments using this technology. Such actions finally convinced various organizations in India about the potential of this technology for a better management of India's renewable and non-renewable resources. The National Remote Sensing Agency (NRSA), the National Natural Resources Management Organization, and the proposed Indian Remote Sensing Satellite (IRS) are developments consequent to his pioneering and continued efforts.

Pisharoty was the first Director of the Institute of Tropical Meteorology, Pune (1962-1966). He organized it from scratch, scientifically and administratively.

He was appointed as a Professor at the Physical Research Laboratory in 1966 to look after rocket and satellite meteorology work. He became a member of the Twelve Member Joint Organizing Committee (JOC), jointly set up by the World Meteorological Organization and the International Council of Scientific Unions. JOC had been set up for planning and organizing a Global Atmospheric Research Programme (GARP). As the only member from tropical countries, he convinced the committee that the Indian summer monsoon played a significant role in subsequent weather events elsewhere in the world and that it was not a mere regional phenomenon—a major land- and sea-breeze. Consequently, the JOC included and planned a Monsoon Experiment (MONEX 1979) as an integral part of the First GARP Global Experiment (FGGE).

Pisharoty's research work spanned the

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following areas: Optics, Ultrasonics, X-rays, Thermodynamic diagrams, Thunderstorms, Kinetic energy of the atomosphere (a thesis on which secured him the PhD degree of the University of California, Los Angeles), Poleward transport of sensible heat on global scale, Monsoon theories, Monsoon and western disturbances, Monsoon depressions and tropical cyclones, Indian standard atmosphere, Magnetic disturbances and magnetic storms, Stratospheric winds and the monsoon, and Application of remote sensing technology in agriculture, in oceanography, and in hydrology.

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S Z Qasim

Qasim began his research career in marine sciences at the Marine Science Laboratories, University College of North Wales, UK, in 1953. He studied the ecology of fishes of the North Sea and Irish Sea and formulated some general principles governing the breeding cycles of the Arctic-boreal and Mediterranean-boreal fishes. He also carried out studies jointly with Prof Knight-Jones on pressure sensitivity of marine animals, which provide a new mechanism of depth regulation in marine animals.

On his return to India, he started working on fresh water fishes at Aligarh. In 1962, he again became actively involved in marine biological researches and started his studies on primary productivity of the Arabian Sea. His subsequent contributions, which have been acclaimed widely, are on factors governing the primary production in specialized environments, such as estuaries, coral reefs and seagrass beds.

His work on tropical marine ecology and oceanography demonstrated the important role of detritus in recycling of nutrients and as food of fish and invertebrates. He also studied the oceanographic problems of the Laccadive and the Andaman Seas. His evaluations of the biological productivity of the Indian Ocean and the oceanography of the Northern Arabian Sea have been acknowledged throughout the world. He has also contributed substantially to the study and control of marine pollution in the seas around India.

In 1981, he became interested in Antarctic research and since then he has been studying problems related to the chemical and biological features of the Antarctic waters—an area which has gained considerable recognition as the new and rapidly advancing science of "Polar Research" in India.

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B P Radhakrishna

A good part of my active life has been spent in the study of the geology and mineral resources of Karnataka, a region made up of very ancient rocks in the Earth's crust and forming one of the most interesting shield areas of the world.

Although a greater part of my attention in the earlier years was devoted to mineral exploration and the promotion of mineral industries in the state, I did not allow my interest in academic studies to suffer. I chose the Closepet granites as the special field of my study. These young potassic granites form a striking feature in the geology of the granite-greenstone terrain of South India. I pointed out that the granite belt was not a single mass of granite as depicted in the geological map, but consisted of multiple intrusives into the Peninsular gneiss. Several varieties were distinguished, a pink porphyritic type being the most characteristic one. The coarse crystals of pink and grey microcline which impart a porphyritic character to the granite were shown to be really porphyroblasts and to have grown *in situ* as a result of potash metasomatism through influx of late stage potash-rich solutions along a belt of structural weakness. I studied this problem first in 1956 and was awarded the PhD degree by the Mysore University for this work.

The southern Indian shield being one of the most ancient land areas of the world presents a variety of landforms. I was particularly fascinated during the early years by the study of landforms and scenery of the Mysore Plateau. The prevailing idea was to consider the Mysore Plateau as an ancient peneplain which had remained unaffected by later earth movements. In a series of papers, I projected the idea that several erosion surfaces can be identified dating back to Jurassic times, clearly pointing to intermittent uplift of the Peninsular region since that period. The Western Ghat was shown to represent the edge of an upraised and disrupted continental block during Miocene times. Drainage anomalies in the western and eastern parts of the Peninsula were shown to be largely the result of vertical movement of blocks during Tertiary and Recent times.

After I assumed charge as Director of the Department of Mines and Geology in 1965, the development of our groundwater resources drew my attention. A large part of the Indian shield is made up mainly of hard rocks. These had been rejected as unsuitable for large scale groundwater development. I pointed out that hard rocks are traversed by deep fissures and fractures and that the upper weathered mantle did function as a reservoir capable of storing and yielding water not only for domestic but also for irrigation purposes. Several seminars were organized to

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highlight this fact and a massive study of groundwater availability was initiated. A separate Ground Water Department was organized to undertake the study. There are a number of features about groundwater movement in hard and fissured rocks which are still not clearly understood and a great deal of research effort is needed. The total available groundwater potential has yet to be assessed properly.

Nowhere else in the world has such large scale development of groundwater been attempted as in the hard rock areas of India. Extensive data being gathered every year need to be stored, digested and analysed for meaningful conclusions to be drawn. Universities and technological institutes should develop interest in studies relating to groundwater hydrology. The determination of age of groundwater is another subject which requires attention. We must be sure whether we are utilizing an annually replenishable resource or mining a resource which has taken years to accumulate.

I subscribe to the view that "small is beautiful" and have not been able to reconcile to the gigantomania syndrome afflicting the development of our mineral industries. India for its size is blessed with a wide variety of mineral resources, which can meet most of our needs. Instead of exploiting them, we have neglected them as small and uneconomical. An unhealthy interest is evinced in exporting minerals in the raw state. Resource utilization, it is forgotten, is an important factor in economic development. In 1965, I developed, as a first step, a small prospect for base metal at Chitradurga. Within a year, a plant capable of treating 250 tonnes of ore per day was erected and commissioned. Such efforts need to be multiplied and a number of base metal prospects in the country brought into the stage of production.

I was not satisfied with producing just concentrates, but was keen on producing the metal. Hydrometallurgy offered the best way of achieving this objective. A successful way for digesting the refractory copper sulphide in ferric chloride solution and recovering copper powder electrolytically was developed. Pilot plant scale experiments were completed. This effort required to be pursued with vigour. In recognition of these and other activities, the Government of India gave me the National Mineral Award in 1971 and the State Government, the '*Rajyothsava Prashasti*'.

I took the initiative along with a few others in 1958 to start the Geological Society of India with its headquarters at Bangalore. The Society has now completed 25 years of its existence. One of its important activities is the issuing of a monthly journal, which has come to be recognized as one of the leading earth science journals of the world. Prof. L Rama Rao was the first Editor. I took over as Editor of this Journal in 1974 and am continuing in that capacity. No other work has given me greater satisfaction and a sense of fulfilment than the work I have been able to do for the Society, first as secretary and later as editor of the journal.

In my pre-occupation with administrative duties, I have not neglected the study of the Precambrian geology of Karnataka State. I have already alluded to my work on the Closepet granites. In 1963, I put forward the view that in Karnataka, we can recognize a schistose sequence older than Dharwar. Subsequent field work and geochronological work has now firmly established the existence of two greenstone successions. I have in two recent summaries, first in 1979 and then again in 1983, reviewed the present status of our knowledge about the oldest rock formations forming part of the South Indian shield. This has now come to be reckoned as one of the best known Precambrian terrains of the world.

In my retirement I have taken interest in the study of crustal evolutionary processes—how the earth separated from a cloud of dust to become a planet circling round the sun, how atmosphere and hydrosphere first developed on the cooling earth, how life evolved and developed, and how crust mantle and core got separated. The development of ideas about continental drift and its present-day counterpart, plate tectonics, the flight of India from the south of equator to its present position, its collision with the Asian landmass resulting in the elevation of the Himalayas, have interested me. The study of the earth as an integrated whole has fascinated me and I am spending the evening of my life in piecing together the knowledge gained and making it available to my younger colleagues in the form of a book: "*Glimpses of the New Geology*".

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R G Rastogi

Rastogi started his research career in 1951 under the guidance of late Prof. K R Ramanathan. His initial studies were concerned with the propagation of radiowaves during solar eclipses, culminating in a detailed report on the subject. He was responsible for the installation of the world famous ionospheric station at Ahmedabad which continued uninterrupted operation over the period 1953-1980 and is credited with many discoveries on the ionosphere at low latitudes. The geomagnetic control of the quiet day as well as disturbed day variations in the ionosphere were among the major problems tackled by him during earlier years. His critical investigations of the global data on f_0F_2 led to the hypothesis of equatorial fountain theory of the F region. His studies on the lunar tides on f_0F_2 not only indicated a very close relationship between geomagnetism and ionosphere at low latitudes but also predicted the longitudinal inequalities in equatorial electrojet currents later verified by rocket experiments in India and Peru.

In 1963, Rastogi organized and established another ionospheric research station at Thumba at the advice of late Prof. Vikram A Sarabhai. In a short span of five years, this station made a host of new discoveries on equatorial electrojet, plasma irregularities, dynamical and storm effects in the equatorial ionosphere. These data led to the discovery of the new phenomenon of kink at equatorial ionosphere.

He has contributed significantly to the phenomenon of counter-electrojet regarding its latitudinal and longitudinal solar cycle effects. He was the first scientist to show a very intimate association between the variations in the geomagnetic and ionospheric conditions at the equatorial electroject region with the interplanetary magnetic field, thereby giving rise to a new field of ionospheric-magnetospheric coupling.

With the emergence of satellite era, Rastogi took up the problems of satellite communications by studying the phase and amplitudes of radiowaves radiated from low orbiting as well as geostationary satellite on HF, VHF and UHF bands at different latitudes and longitudes. He was responsible for the installation and operation of one of the most sophisticated satellite receiving stations at Ootacamund in collaboration with the National Bureau of Standards of USA in 1975-76 at the time of SITE experiments by ISRO of India and NASA of USA and obtained a unique set of data on electron content and scintillations at low latitudes, not duplicated anywhere else in the world.

Rastogi has always been an advocate of university partnership in research plans of

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national research laboratories and had helped to develop research activities at a number of university centres like Tiruchirapalli, Madras, Udaipur, etc. During 1975-76, he organized a national project on satellite radio communication studies involving a number of universities.

He has visited major ionospheric groups in the world and has published papers jointly with scientists from USSR, France, USA, Peru and England. He has been visiting scientist at National Research Council, Ottawa; National Bureau of Standards, Boulder, USA; Jicamarca Radio Observatory, Lima, Peru; University of Texas, Dallas, USA; Centre of Radio and Space Research, Paris; and Air Force Research Laboratory, Boston, USA.

Since 1980, Rastogi has been Director of the Indian Institute of Geomagnetism with its headquarters in Bombay and field observatories distributed all over India. His main effort has been to develop this institute into a national centre for research in geomagnetism and aeronomy utilizing the special environment of India for using geomagnetic method for studies on solid earth and space physics.

Rastogi has been member of a number of international research committees and is presently a member of the Executive Committee and Chairman, Inter-Divisional Commission for Developing Countries of the International Association of Geomagnetism and Aeronomy.

He has supervised over 20 students for PhD and has published over 300 research papers on ionosphere, geomagnetism, radio communications, magnetosphere and allied subjects.

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Amalendu Roy

Roy was educated at Calcutta and Dacca Universities, and at the Colorado School of Mines, USA. He has served the Geological Survey of India; Indian Institute of Technology, Kharagpur; Oil and Natural Gas Commission, Dehradun; National Geophysical Research Institute, Hyderabad; and the United Nations (as an expert in applied geophysics in Brazil and Nigeria), and is currently a Professor of Geophysics, University of Ife, Nigeria. He is a specialist in exploration geophysics and has had extensive experience in teaching, research, field surveys and management in this discpline. The more important of his research contributions are discussed below in brief.

Geophysical Interpretation and Field Techniques

In the pre-digital days of manual computation, an optical device was designed for determining the gravitational and magnetic fields for three-dimensional bodies, based on the fact that all these three fields obey the inverse square law[1]. Through theoretical analysis and laboratory modelling, a procedure was established for the quantitative interpretation of self-potential measurements over sheet-like mineralized veins. The relaxation method was applied for upward continuation of gravity and magnetic data. A simple integral transform was devised for handling gravity and magnetic anomalies caused by bodies that are neither point poles nor infinitely long line poles[2]. In general, this transform converts a three-dimensional field into a two-dimensional one without altering the essential body parameters. Two new interpretation techniques were developed for use in telluric field and self-potential surveys[3]. Methods were developed for the interpretation of gravity and magnetic data collected over uneven topography, in boreholes and over inclined surfaces. Extensive theoretical, analog model and field investigations were carried out towards the development of the two-electrode array as a more efficient tool in resistivity and induced polarization surveys[4,5].

Important New Concepts

The problems of non-uniqueness in geophysical interpretation was investigated in depth and detail[6]. The gravity and magnetic methods are non-unique, not because these fields are derivable from a scalar potential function, as is generally believed, but because the unknown parameters of the ground greatly exceed the independent observables. Geophysical methods, including the seismic methods, can yield unique interpretation only when the number of unknowns is reduced drastically to a manageable level by using extraneous information on the shape and physical property of the sources.

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The method of analytic continuation was originally developed for application only to gravity and magnetic data in oil exploration. This position was substantially expanded with the following new contributions[3,7–10]: (i) The technique can be applied to other geophysical methods as well, such as, self potential, low frequency or dc telluric, and electromagnetic data in non-conducting media; (ii) The method is more generally useful in exploration for hardrock minerals rather than petroleum, because the shapes of hardrock ore bodies are usually such that the onset of oscillations in the downward continued field occurs near their top; (iii) The region of validity for convergence of the continued field was formally established; and (iv) The problem of analytic continuation of general electromagnetic fields—for arbitrary frequency and ground conductivity—was solved for the first time.

In the field of direct currents, a new theorem was formulated[11] that expresses the measured signal, a potential difference, for an arbitrary ground as the sum of the dipolar contributions from the volume elements of the entire space. This allows one to examine an observed resistivity anomaly in terms of the constituent fractions originating in different ground compartments, such as the target itself, host rock, overburden, etc.[12]. This also led to an objective definition and determination of the depths and radii of investigation in various resistivity and induced polarisation arrays in ground surace as well as logging work[13,14].

A general formula, supported by a practical computational procedure, was derived for transforming an observed magnetic map for any component, at any latitude and for any given direction of magnetisation into another for which any one or two or all the three parameters differ. Baranov's reduction to pole and Lourence and Morrison's computation of vector magnetic anomalies in an area from measurements on a single component in that area are but two particular cases of this general transformation. Three new magnetic transformations were specifically brought out: (i) reduction to equator, (ii) orthogonal reduction, and (iii) elimination of remanence. All these transformations simplify magnetic interpretation by promoting symmetry and zero lateral shift[16].

Geophysical Well Logging

Various kinds of focussed resistivity logging devices have been and are being widely used all over the world for nearly 35 years. Extensive theoretical and analog model studies[15], however, demonstrate conclusively that focussing has no inherent advantage and that the response of a focussed tool—which is considerably more expensive—can be synthesized rather closely from that of the conventional two-electrode resistivity logging sonde. Any focussed array has a reciprocal that is unfocussed but has exactly the same reponse.

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Supriya Roy

Roy's major research efforts have been directed towards establishing and interpreting the geochemical, mineralogical and genetic characters of manganese deposits occurring in diverse geologic settings. His major contributions in this field are summarized below.

(1) Metamorphosed Manganese Deposits of India

(i) Determination of the precise geologic setting and metamorphic regime of the Precambrian manganese formations of type areas of the Sausar and Khondalite Groups and the Aravalli Supergroup.

(ii) Determination of the specific mineral assemblages and characterization of the metamorphic fabric in these ores as an expression of metamorphic modification under different P-T conditions.

(iii) Determination of the trend of element partitioning in coexisting manganese oxide minerals (in ores) and manganese oxide and silicate minerals (in Mn silicate-oxide rocks) with progressive metamorphism.

(iv) The finding that Mn-rich rocks undergo prograde deoxidation (though essentially at high fO_2) in contrast to prograde dehydration-oxidation (at much lower fO_2) in the associated pelites, establishing that the composition of the fluid phase in the contrasted environments was internally buffered by the reacting minerals.

(v) Systematic mineralogical determination of the Mn-bearing silicates (blanfordite, manganoan diopside, brown Mn-pyroxene, winchite, juddite, tirodite, alurgite, manganophyllite, etc.) of the Mn silicate-oxide rocks, establishing thereby the firm nomenclature and identity of these varietal types.

(vi) Petrogenesis of the Mn silicate oxide rocks of different metamorphic grades and determination of their pre-metamorphic character.

(vii) Establishment of generalized mineralogenetic trends of the Mn oxide ores and the Mn silicate-oxide rocks in prograde metamorphic conditions of varying P-T and fO_2 and deciphering of the pristine character of the ores.

(viii) Comparison and correlation of the results of the above studies with those on the metamorphosed manganese formations occurring elsewhere in the world and working out of a generalized model for metamorphism of Mn-rich sediments of varying bulk composition under different metamorphic conditions.

(2) Studies on Unmetamorphosed Sedimentary Manganese Deposits of India

The manganese ore deposits of the

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Archean Iron Ore Group (Bihar & Orissa), Dharwar Supergroup (Karnataka) and the Proterozoic Penganga Beds (Maharashtra) were studied, with particular reference to their genesis, environment of deposition and diagenetic modifications. The deposits of Iron Ore Group, recognized as possibly the oldest in the world (3200-2950 Ma), have been firmly established to be syngenetic sedimentary in contrast to the earlier concept of their supergene derivation. The typical diagenetic fabric of the low temperature Mn oxide minerals of these ores has been established; the field relations and chemistry of the ores suggest their terrigenous source. The other Archaean deposits of Chitradurga Group (Dharwar Supergroup) enclosed in cherts and shales have also been ascribed a shallow-water nonvolcanogenic sedimentary origin, rejecting the earlier theory of their supergene derivation.

The sedimentary Mn oxide ore deposits of the Proterozoic Penganga Beds of Andhra Pradesh were studied by Roy and his associates with respect to the geologic setting, basinal configuration, associated litho-types, geochemistry, mineralogy and textural fabric. These ore bodies, unique in type in India and in the rest of the world, have been established to have formed in shelf environment in a Proterozoic transgressive sequence in the Godavari rift valley, interlaminated with chert and enclosed in limestone without a trace of volcanism or hydrothermal activity in the sequence. Evidence of contemporary biological activity, directly or indirectly related to ore formation, has been established. The ores retain partly their pristine character, showing todorokite and birnessite as the principal phases (as in modern marine deposits) as well as frozen stages of diagenetic modification in mineralogy (manganite, braunite, bixbyite and minor pyrolusite and psilomelane) and the fabric.

(3) Integration and Synthesis of Data on Manganese Deposits of India and Other Parts of the World for Defining Generalized Genetic Models

A detailed interpretative analysis of data on the genesis of manganese deposits in different geologic settings and their post-depositional modifications, taking the major world examples, including those from India, has been done. Roy has been working as the global leader of the UNESCO sponsored International Geological Correlation Programme (IGCP) Project No. 111: Genesis of Manganese Ore Deposits since 1978. Under this collaborative work, all aspects of manganese deposition in space and time have been examined and the genetic models in different geologic settings refined. The results of these integrated studies are summarized below.

(i) The global metallogeny of manganese as related to the progressive development of the earth's crust with time has been examined critically.

(ii) A broad-based classification of the land-based manganese deposits of the world, based on genesis, source of metals and lithologic/tectonic association has been established and all types have been characterized.

(iii) Different aspects of manganese deposits on the modern sea- and lake-floors have been reviewed and the multiple parameters acting cumulatively or interfering with one another to generate these deposits have been identified. The ancient analogues of these deposits on land have also been taken into account to build a link between modern and ancient processes of manganese deposition.

(iv) The generalized mineralogenetic trend of manganese oxide and silicate minerals in different world deposits in varying grades of regional and contact metamorphism in different P-T, fO_2 and fCO_2 conditions has been established.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

A K Saha

As a Professor at Presidency College, Saha has carried out extensive research on various aspects of petrology, geochemistry, Precambrian stratigraphy and geomathematics. He has guided the researches of a large number of PhD and MSc students.

Saha has carried out extensive research in three distinct fields: (i) Petrology, geochemistry and Precambrian crustal evolution, (ii) application of statistical techniques in problems of petrology and mineral exploration, and (iii) problems of the environment, particularly those relating to air pollution, water pollution and groundwater management.

Saha's important contributions are discussed below in brief.

(1) He carried out intensive studies on the history of emplacement of three granitic plutons in SE Ontario, Canada, using structural, petrological and decrepitometric methods. In this connection, he provided a new explanation for the so-called "Basic Front" around many bodies of granite.

(2) He carried out intensive investigations on the structure, petrology and geochemistry of the Singhbhum Granite, which has been proved to be a composite body with a large number of magmatic units emplaced in three distinct phases and several bodies of granitized basic metamorphics, as well as relics of still older granites (about 3800 Ma old). This discovery of the oldest crust so far known in India and in the entire eastern hemisphere was hailed as a major contribution to our knowledge of the early evolution of the earth's crust. For the first time in India, the detailed history of emplacement of a large batholithic body of granite as well as stages of the early crustal evolution has been deciphered.

(3) In collaboration with Prof S N Sarkar, Saha made a thorough revision of the Precambrian stratigraphy, tectonics and geochronology of Singhbhum region. As a result, this region is now considered to be a model area of the Indian shield where the detailed geological history of a vast span of time ranging from 3800 to 900 ma has been worked out.

(4) Saha carried out a systematic study of the mineralogy, geochemistry and history of crystallization of some pegmatites of Bihar Mica Belt. He put forward a hypothesis based on the role of fluid pressure during crystallization of pegmatites for the genesis of muscovite books. He indicated several simple geochemical criteria for the identification of muscovite-bearing pegmatites; these criteria are now being widely used by the Geological Survey of India and other agencies in prospecting for muscovite.

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(5) In recent years, Saha has initiated research on the problems of the environment in India. Baseline studies on air quality carried out under his guidance in parts of southern Bengal have yielded valuable information on the nature and magnitude of air pollution, particularly over the rural areas. The natural processes determining the distribution and migration of the pollutants have been identified and assessed through the use of techniques of factor analysis. Ingenious use of multivariate statistical techniques in the analysis of water pollution parameters has helped evolve an optimum plan for water pollution monitoring of the Ganga. Together with A B Biswas, he has demonstrated the beginning of land subsidence in parts of Calcutta, caused by continued subsidence of piezometric surface of the confined groundwater.

(6) Saha pioneered in India the geological application of statistical techniques, including the use of trend surface analysis as well as the multivariate techniques of discrimination analysis, multiple regression modelling, cluster analysis and factor analysis to throw new light on the various processes involved in the genesis of granitic rocks; he also developed the new technique of grid deviation maps—a variant of the moving avarage analysis. He has put forward an ingenious hypothesis on the use of areal composition variation patterns of granite bodies for assessing their mineralization potentiality, particularly for the search of the cogenetic china clay deposits within the Singhbhum Granite. He has made pioneering contributions to the use of geomathematical technique for (i) indicating new ore shoots in the Champion Lode of Kolar Gold Field, and (ii) identification of the phases of mineralization in the Singhbhum Copper Belt.

Saha is the author or co-author of 95 research papers published in reputed journals in India and abroad, in addition to numerous semi-popular review articles and one book on air pollution. Results of his work have been widely referred to in India and abroad, including a number of standard text and reference books.

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S K Sen

Sen has addressed problems which bear on chemical and mineralogical evolution of metamorphic rocks and bring out the interaction of physics and chemistry during the transformation of important crustal rocks. The approach has been through (i) studies on the composition of common silicate solutions, such as plagioclase, garnet, biotite, pyroxenes and hornblende, (ii) analysis of the fractionation patterns of common elements (particularly Fe and Mg) between coexisting minerals, and (iii) exploration of the relationship between mineral chemistry and rock chemistry.

Sen's early contributions were exploration of the significance of antiperthites and the controls on the solubility of K, Ba, Sr, Fe and Ti in plagioclase feldspars; tracing of metamorphic reactions in a suite of progressively metamorphosed pelites and correlating the partition coefficients of Mg-Fe between garnet and biotite with metamorphic grade; analysis of the role of hornblende in the exchange equilibrium, with respect to Mg and Fe, between two pyroxenes in basic granulites; underscoring of the importance of silica activity in the hornblende breakdown equilibria; pointing out the general prograde nature of hornblende in basic granulites, and advancing cooling in selected compositions as the causative factor in stabilizing garnet in basic granulites. In the recent past, on the basis of a comparative analysis, in terms of major and trace element chemistry as well as frozen magmatic signatures in basic granulites, greenstone metabasites and recent basalts, granulite-greenstone relations were elucidated, an orthopyroxene-garnet geothermometer was formulated, and a method of water barometry in cordierite-granulites was devised.

The lines of enquiry that engage Sen's attention currently are related to fluid behaviour during high grade metamorphism, the role of partial melting in the shaping of granulite assembalges in quartzofeldspathic-basic-metapelitic compositions and significance of granulite-massif anorthosite associations.

Insofar as the past predilections influence future enquiries, problems of evolution of granulite terrains, which are widespread in the Indian shield, will continue to receive attention. But as complements to the aspects relating to physical chemistry, the dynamic, historic and geophysical facets will also be explored. These should combine towards providing insights into (i) lower crustal processes, (ii) growth and recycling pattern of the continental crust, and (iii) style of endogenous processes in the Precambrian.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

Saurindranath Sen

Sen was the first to take up research on magmatectonics and petrofabric analysis in India. He elucidated the mechanism and effects of intrusion of a lensoid body of porphyritic granite in Manbhum, Purulia district on the basis of (1) magmatectonic features of the granite, (2) statistical study of joint distribution in the wall rocks, and (3) effects of emplacement of the granite on other megascopic and microscopic fabric of the country rocks[1–3]. This pioneering effort in India fetched Sen a DSc degree, and an offer from the Columbia University, New York, through the Fulbright-Smithmundt exchange programme, to introduce these topics in their curriculum and apply modern techniques of structural geology (as in the early fifties through the work of Sander, Cloos and Wegmann) in their research programme[4].

Sen's work on granulite and amphibolite facies metamorphic rocks in Manbhum[5], especially on some charnockitic assemblages[6,7] and calc-magnesian metasediments and amphibolites[8] has been referred to widely. His two contributions that have attracted wide attention are: (i) explanation of interlayering of calc-silicate rocks and amphibolites by metamorphic differentiation from close and gradational association of the two lithologies, and (ii) derivation of hornblende in some of the charnockitic assemblages from pyroxene, in a retrograde trend.

Sen's interest in the response of single crystals in a rock volume to changed stress environment, and their recrystallization at raised temperatures, led to a study of deformed labradorite plagioclase crystals in a banded norite from Oregon, USA. Planes of gliding were located crystallographically and verified from the structure and packing of the mineral[9].

In the field of Precambrian geology, the work on a part of the Holenarsipur schist belt of Karnataka indicated an approach towards appreciation of stratigraphic relations of the rocks which was different from the hitherto practised methods in the region and yielded results significantly different from those of earlier workers, except for a tectonic-cum-petrogenetic interpretation offered later from landsat imagery by Drury[10]. Sustained work on the structure, tectonics and stratigraphy of the rocks of the Aravalli Range and its environs started with a detailed investigation of the structural geometry of selected areas in the region by Sen[11] and his colleagues. Structure mapping, traverse across the Range, reconnaisance mapping in the intervening tract and study of aerial photographs have yielded a comprehensive picture of the tectonic set-

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up of the Range, necessitating a drastic change in the stratigraphic reconstruction and reconstruction of the structural history of the crystalline Precambrians of the region[12,15]. The most important result that has emerged from this study is the identification and mapping in the Aravalli Range of several parallel NE-SW trending independent tectonic units. The temporal relationship of these tectonic zones pictured from the structural studies has received corroborative support from geochronologic work of Prof. Gopalan and his group. The tectonic history of the Proterozoic mountain belt and the temporal and genetic relationship of the tectonic zones within the belt have been traced in the light of the plate tectonic paradigm. The identifiction of a Palaeosuture (a Proterozoic subduction) east of the Delhi belt and west of the belt was among the earliest such demonstrations from the Precambrian tracts[12-15].

Results of geomorphological studies through aerial photographs, morphometric analyses, selected river valley analyses and characterization of sediments of their flood plains, leading to the recognition of several geomorphological provinces, were utilized in interpreting recent movements in the Aravalli tract that was triggered off by a post-Neogene reactivation of Precambrian fault surfaces. This movement was ascribed to the stress generated on the frontal part of the Indian continental plate and, to some distance back, by the continent:continent collision involved in the closing stages of the Himalayan orogeny. A quantitative analysis, based on some basic assumptions of the rheologic behaviour of the crust and the mantle and on the known extent of differential movement, yielded reasonable results for the physical parameters of the elements participating in the process[16].

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S Sengupta

Sengupta's contributions to earth sciences (sedimentation and stratigraphy) comprise regional studies in several sedimentary basins of India, laboratory investigations of some sedimentary processes and development of methodology for sedimentological research.

Regional Studies in Sedimentary Basins

Through coordinated geological-geophysical investigations, Sengupta unravelled the subsurface geological configuration of a large part of the Bengal basin, identified the tectono-environmental units (stable shelf, miogeosyncline, etc.) of this basin, and interpreted the tectonic and depositional history of the Bengal-Assam region during the Tertiary[1]. He also indicated the possible nature of the subsurface geological structures below parts of the Gangetic plains through a review of geophysical data[2].

In the Godavari valley, Andhra Pradesh, Sengupta deciphered the depositional environments and palaeocurrent systems of the Gondwana sediments from various lines of evidence. In the course of lithostratigraphic mapping of the Gondwana rocks, he subdivided the Kamthi Formation into three distinct members and also discovered the stratigraphic equivalent of the Ironstone Shale Formation in this basin. He also worked out the stages of shift in the direction of transportation of the Kamthi sediments through time[3,4].

Sengupta's finding that the Permo-Triassic rivers responsible for Gondwana sedimentation in the Godavari valley used to flow in a direction nearly opposite to the present day rivers in the same valley, has far-reaching significance. His discovery of uninterrupted fluvial sedimentation during the Upper Paleozoic and Mesozoic, together with his finding of lithofacies variations within the Gondwana stratigraphic units, led to the formulation of a new model for Gondwana sedimentation through lateral shifting of river channels[4].

The results of Sengupta's studies in the Bengal basin are used widely in connection with exploration for petroleum and for onshore-offshore stratigraphic correlation in the Bay of Bengal region. His stratigraphic studies on the Gondwana deposits of the Godavari valley have aided in the prospecting for coal and ground water in this valley. Banerjee and Sengupta's reconnoitory studies on the depositional environments and palaeocurrent systems of the Vindhyan deposits[5] have led to intensive sedimentological investigations of these deposits by a number of workers.

Studies in sedimentary basins prompted

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Sengupta to develop the methodology for sedimentological research and also to undertake investigations of some of the basic sedimentary processes through controlled laboratory experiments. A brief account of his major contributions to these fields is given below.

Development of Methodology for Sedimentological Research

The technique of lithology-velocity-seismic reflection correlation used by Sengupta in the fifties, for subsurface stratigraphic investigation in the Bengal basin, has proved to be the forerunner of the methodology for 'seismic stratigraphy' developed nearly 20 years later.

Sengupta's finding that the orientation and plunge of long axes of pebbles vary according to their location on a cross-stratified unit, led to modifications of the commonly used technique of paleocurrent analysis[6]. His collaboration with statisticians and mathematicians led to the development of the following techniques which have found wide application in sedimentological research:

(i) Techniques for sampling and analysis of directional data and their application in palaeocurrent studies[7–9].

(ii) A technique for the analysis of "weight frequency data" and its application to the results of sieving[10].

(iii) A technique for computation of suspended loads for given source materials and flow parameters[11].

Experimental Investigation of Sedimentary Processes

Flume studies conducted by Kuenen and Sengupta[12] led to the significant conclusion that the capacity and competency of a suspension load are interrelated.

Subsequent experimental studies by Sengupta have provided an insight into the mechanism of grain sorting responsible for the generation of log-normal grain size distributions commonly observed in nature[13,14]. His finding that the grain size distribution of a suspended load is related to flow velocity, height of suspension and the nature of the bed (source) material led to the development of a new technique for computation of suspended load. These studies have provided new clues to the interpretation of log-probability plots of grain sizes[15] and have also led to investigations on similar lines in advanced laboratories abroad.

Current Studies and Future Plans

Sengupta has designed and constructed a closed circuit hydraulic flume of an uncommon type at the Indian Statistical Institute (ISI), Calcutta, for conducting experiments on transportation and deposition of sediments by suspension currents. Experiments conducted in this flume in collaboration with J K Ghosh and B S Mazumder of ISI have led to the conclusion that all the grain sizes in suspension (not the coarsest ones only, as is commonly believed) are deposited simultaneously when the flow velocity is reduced[16]. Sengupta, Ghosh and Mazumder are currently engaged in an investigation of the processes responsible for this phenomenon. Their future plan includes development of a technique for paleo-flow interpretation, using the experimental findings as clues.

Sengupta is continuing his field studies in the Gondwana basins of India. In collaboration with his students, he is also conducting research on present day fluvial processes with a view to obtaining insights into the mechanisms responsible for ancient fluvial sedimentation.

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H N Siddiquie

Early Contributions

Siddiquie started work in marine geology at a time when research vessels were not available in India. Thus, his earlier studies were unavoidably based on navigational charts and data and samples collected by foreign vessels in the Indian Ocean. Subsequently, he developed indigenous techniques and facilities to work at sea.

Siddiquie's studies on the sediments (*RV Ob* and *RV Vityaz* collection) from the Bay of Bengal resulted in important contributions which are widely referred to in the literature[1]. The Scripps Institution of Oceanography invited Siddiquie to participate in the Deep Sea Drilling Project in the Arabian Sea. His studies of Site 219 indicated that the Paleocene acidic tuffs represent a phase of Deccan Trap activity on the Laccadive Ridge before its subsidence and separation (Lower Eocene) from peninsular India. During the subsidence, briefly phosphorite and manganese-rich sediments were deposited from upwelled waters[2,3].

Siddiquie and colleagues prepared a Bottom Sediment Map of the Seas Bordering India (15,000 bottom notations and 3200 bottom samples). This is the first attempt in the country to prepare offshore geological maps and depicts many interesting features of the continental margin and is of considerable value in planning offshore exploration[4]. Siddiquie and coworkers prepared a geomorphological map of the NW Continental Margin based on the echograms of *INS Darshak Expedition*. The seamounts with a steep scarp on the slope probably indicate ancient valcanoes and fractures[5].

Siddiquie developed facilities for marine geological work and offshore mineral exploration from boats in shallow areas. He demonstrated the usefulness of mineralogical studies of a number of samples on a grid to decipher long-term sediment transport[6,7]. He developed indigenous simple and cheap techniques for fluorescent tracer studies of sediment transport in coastal areas, which are important for designing of coastal structures[8,9]. The detailed surveys (1 : 5000 and 1 : 10,000) of Lakshadweep indicated that the (i) cyclones from the east (forming storm beaches) and the sediments transported during the SW monsoon are important in the building of the island on the E reefs of the lagoons, (ii) the high MgO in the sediments of the reef margin indicates its source in the reef, and (iii) submerged terraces on seaward reefs were formed during low sea level. The dates of storm beaches clustering 3000-2000 years BP and 500 years BP to the present time indicate variation in the frequency of the storms. These also suggest that parts of the islands have

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grown by about 30 m in the last 2780 years to 100 m in 470 years[10]. The total reserves of calcareous sediments to a depth of 2 m are of the order of 1400 million tonnes. Similar surveys (bottom sampling, bathymetry, seismic profiling and magnetics) recently carried out off the Konkan coast indicate the extension of the ilmenite deposits to offshore and the reserves appear to be large[11]. These form the first successful projects for offshore surficial mineral exploration in the country. Siddiquie was invited to review the surficial mineral deposits of the continental shelf at an International Seminar at Orleans, France[12].

After the commissioning of *RV Gaveshani*, Siddiquie initiated integrated geological and geophysical surveys and by now more than two-thirds of the western continental shelf has been covered. The studies indicate that (i) Deccan Traps are exposed on the seabed to a depth of about 15 m off Bombay, (ii) the seabed in the Southern Gulf of Khambhat is covered by thick clays which thin towards the north where the N-S and NNE-SSW sand banks are exposed and the intervening channels are filled with clays, and (iii) the banks have been formed parallel to currents, while the ripples and mega ripples (E-W to ENE-WSW) are formed in layers of mobile sand transverse to the currents[13], (iv) acoustic masking due to gases in sediments in an area of 2500 sq km[14]; and (v) occurrence of amphibolites on the Western shelf.

As an application of marine geological and geophysical studies to the development of offshore oilfields, Siddiquie and coworkers covered the entire spectrum from pre-drilling to post-construction surveys. The surveys initiated in 1976 involved accurate position fixing, bathymetry, side scan sonar, shallow seismic profiling followed by seabed sampling and analyses and interpretation of the data. The surveys in deeper areas were carried out on *RV Gaveshani* and in shallow areas on small boats. These included the surveys for the pipeline route from Bombay High to Bombay, Bombay Floating Light to Karanja. Bassein to Gujarat, its shore approaches and from Direction Bank to Murud and Janjira. The bathymetric and shallow seismic surveys of Bombay High, South Bassein and Direction Bank were carried out for designing and siting of platforms. These were followed by the post-lay survey of the Bombay High to Bombay pipeline. The pipeline from Bombay High to Bombay was laid on the route recommended by the Institute.

Siddiquie and coworkers also surveyed and advised on the route for effluent disposal pipeline for Bombay Municipal Corporation, Zuari Agro-Chemicals, Kudremukh Iron Ore Co., Ballarpur Industries and Travancore Titanium Products and for the development of ports and harbours at Visakhapatnam, Mormugoa, Mangalore, Karwar and Tuticorin.

Recent Contributions

First Indian Expedition to the Antarctica : As Deputy Leader of the First Indian Expedition to Antarctica, Siddiquie planned, organized and coordinated the Marine Sciences programme for the cruise under the overall guidance of Dr S Z Qasim. With the successful landing and completion of marine research programmes, the country joins the select group of developed (and some Latin American) countries carrying out scientific work in the Antarctica. The marine surveys led to the discovery of Rift Valleys on the Antarctic Continental Margins[15].

Polymetallic Nodules in the Indian Ocean : Realizing the importance of the polymetallic nodule deposits on the seabed, Siddiquie analysed the data and samples collected by other countries[16] and identified areas for exploration[17]. He initiated planning in 1977 and the first cruise for the exploration of polymetallic nodules was successfully organized on *RV Gaveshani* in 1981. The achievement has been recognized as a major landmark in India and abroad. This, in turn, led to the recognition of India as a Pioneer Investor along with France, Japan and the USSR and four other entities controlled by other countries, i.e. USA, FRG and UK (UK Conference on the Law of the Sea, 1982). As a result of this recognition and the need to identify a Pioneer Area before the end of 1982, the CSIR/DOD have launched a vigorous programme for surveys for polymetallic nodules in the Indian Ocean. Siddiquie is now coordinating this programme in which a number of ships (*RV Gaveshani, Orv Sagar Kanya* and two chartered vessels) where engaged in surveys and more than 19 laboratories are involved in the analyses of the data and samples. The vessels have already covered an area of over 3 million km in the most promising area of the Central Indian Ocean and collected a vast amount of data and samples. Based on the results of these extensive surveys, the country (India) filed the claim for the Pioneer Area with the United Nations in January 1984.

In recognition of his contributions, Siddiquie was awarded Padma Shri in 1983. He won the S S Bhatnagar Prize in Earth Science in 1978.

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B L K Somayajulu

Naturally occurring radionuclides are of two origins: (i) Primordial which have been present since the formation of the earth like U and Th or their daughter products like ^{230}Th, ^{226}Ra, ^{210}Pb, etc., and (ii) cosmogenic radioisotopes produced in the atmosphere by the interactions of protons and neutrons (from cosmic rays) with N_2, O_2 and Ar contained in the atmosphere. Based on their half lives and chemical properties, one can use these radionuclides to study many of the processes that take place on the earth and in the oceans. To be able to apply radioisotopes to study processes, one should know their production rates, distribution and behaviour in the various spheres of the earth, viz. atmosphere, hydrosphere, lithosphere, etc. The research programmes pursued by Somayajulu over the past two decades centre around these aspects. The main thrust has been on two cosmic ray produced isotopes, ^{10}Be (half life = 1.5 my) and ^{32}Si (half life = 108 yr), principally to study marine processes.

Work on ^{10}Be

Earlier work centred around precise measurements of this nuclide in marine sediments to obtain accumulation rates of deep sea sediments and its detection in marine manganese nodules—a sea bed resource which has been studied the world over in great detail. The technique for the detection and measurement of the beta activity of the nuclide involved the use of a flow-gas type GM counter with low background and high stability and efficiency. Though this method involved the analysis of hundreds of grams of deep sea sediment and tens of grams of manganese nodule material, extensive studies on this nuclide were carried out on both manganese nodules and deep sea sediments. It has been established that the nodules grow at mm/10^6 yr and sediments at mm/10^3 yr and that these rates compare well with the rates obtained by other techniques. In fact, it has been shown that ^{10}Be is the best nuclide for dating oceanic manganese nodules. In the case of marine sediments, it has been shown that precise cosmic ray intensity variations can be determined by making precise ^{10}Be measurements on well-dated marine sediment cores. In addition, measurements of NRM intensities and reversal of the earth's magnetic field will help to delineate the variations in earth's magnetic field intensities from those of CR intensities. In the last two million years, the CR intensity alone varied by ± 52%. A few years ago, with the advent of accelerator mass spectrometry, the sensitivity of ^{10}Be measurements increased by over a million-fold, opening the way for altogether new and exciting applications of ^{10}Be, such as

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determining the recycling time scales of marine sediments after subduction, ages of petroleum, weathering rates of rocks and melt water inputs to the ocean during interglacials. Currently, meltwater input studies are being pursued actively.

Work on ^{32}Si

This nuclide is particularly suited for studying (i) mixing in coastal waters, and (ii) vertical mixing in deep waters. The fallout of ^{32}Si in rains was measured extensively to understand the input function. A technique was developed for the *in situ* adsorption of Si from seawater using which 20 vertical profiles (between surface and 5000 m depth) from the world oceans were collected. The marine geochemistry of this radionuclide is now fairly well understood. The horizontal advection rates of the north Atlantic deep water and Antarctic bottom water could be estimated. ^{32}Si is also used in large lakes to study their mixing characteristics. Some of these studies are still in progress.

Other Programmes

A study of about a hundred gravity cores from all over the Pacific Ocean floor by nondestructive logging technique for magnetic susceptibility revealed that this parameter could be used as a stratigraphic marker.

Study of Indian (tropical) estuaries to understand the biogeochemical reactions that take place in them as well as estimating the soluble and suspended inputs from the rivers to oceans is another programme that is being pursued. Also, extensive studies have been carried out recently on the Saurashtra Quaternary Carbonate deposits to understand their precise ages and origin. These studies have implications for neotectonism, sea-level changes and the emergence of early man in the Saurashtra peninsula.

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M S Srinivasan

As organizer and leader of a team of workers on the Neogene bio- and chronostratigraphy of the Andaman-Nicobar Islands, Srinivasan has been able to establish new methods for a meaningful subdivision of the thick monotonous sequences[1,2]. The sequences on Andaman-Nicobar islands are important because of their strategic position in the northern Indian ocean, an area where few other good Neogene marine sequences exist, except for the deep sea drilling programme (DSDP) sections. By examining a large number of overlapping sections exposed on these islands, Srinivasan has been able to produce an almost complete late Cenozoic sequence of tropical planktonic foraminiferal zones[3–5]. One of the most interesting observations made during the study was to record a close relationship among volcanism, geomagnetic reversals, microfaunal extinctions and volcanically induced climatic changes[6,7]. The contributions made provide necessary data for detailed time-slice studies on the Indian ocean deep sea cores. The studies have further provided basic data of fundamental importance in the exploration of oil and natural gas in the Andaman-Nicobar region[8].

A sustained and intensive research programme on the marine cenozoic sediments of Andaman-Nicobar islands conducted by Srinivasan led to the establishment of a well organized centre for advanced study and research in this branch of earth science in the Department of Geology, Banaras Hindu University.

Contributions of Srinivasan on the Neogene planktonic foraminiferal biochronology have provided a basic clue to the study of the evolutionary trends in this group, which is vital to the understanding of marine sediments throughout the world. For the first time, classification of the group has been treated in a totally phylogenetic or natural order[9]. In a long-term view and also in the immediate future, this type of study would enable stratigraphers to conduct international correlation and dating of Neogene deep sea sediments. The scanning electron microscope has been centrally employed in these studies, which have added much to our understanding of the surface ultrastructure within the planktonic foraminifera. This, in turn, has provided a crucial insight into the complex evolution and paleoceanography of the group. SEM studies conducted by Srinivasan and Kennett[10,11] on *Neogloboquadrina* plexus from the Late Miocene to Recent and over broad regions of the Pacific, Atlantic and Indian Oceans indicate that ultrastructures change consistently with changing latitude and reflect a close relationship with water masses. Thus, the studies suggest that the

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surface ultrastructure is a reliable tool in paleoclimatic and paleoceanographic studies.

An extensive study conducted on all the Neogene planktonic foraminifera from tropical to polar regions using deep sea cores of the deep sea drilling project has resulted in the book *Neogene Planktonic Foraminifera: A phylogenetic atlas*[12]. This volume represents a synthesis of the evolution of planktonic foraminifera during the last 25 m.y. of earth's history for the entire world's ocean.

In addition, Srinivasan has made important contributions in respect of the problems of Cenozoic epoch boundaries, such as Eocene/Oligocene boundary[13], Oligocene/Miocene boundary[14], Miocene/Pliocene boundary[15] and Pliocene/Pleistocene boundary[16], based on massive new data on the evolutionary changes in planktonic foraminifera over the boundary and the changes in the character of the assemblages.

Planktonic foraminiferal counts have been completed for all of the available Neogene South Pacific DSDP sites. These data form the basis for our time-series analyses of south Pacific paleoceanography for the entire neogene (latest Oligocene through Recent) and the latitudinal span from the equator to the subantarctic.

Presently, Srinivasan is working on a project aimed at drawing together a large volume of information on planktonic microfossil biogeography of the Indian Ocean and the southwest Pacific Ocean region during the Cenozoic. The objective of this investigation is not to collate the numerous biogeographic schemes now available for the region as a result of deep sea drilling, but to determine when major biogeographic events occurred during the Cenozoic and to attempt to relate these to paleoceanographic changes.

Deep sea benthonic foraminifera have been found to be associated with distinct water masses in various parts of the oceans. Initially, these investigations were carried out in the North-Atlantic and South Pacific. Although the assemblages in these areas have been shown to be clearly related to specific water masses, it is not always clear as to which individual parameters are of the greatest importance. It is, however, apparent that relatively small variations in abyssal water mass characteristics are by and large different in the faunal assemblages. These relationships thus provide one of the few approaches through which deep water circulation changes can be studied in the deep sea record. Benthonic foraminiferal assemblages may also be sensitive to minor differences in bottom water characteristics and may prove helpful in delineating bottomwater sources. One of Srinivasan's ongoing studies pertaining to Northern Indian Ocean paleocirculation history is related to deep sea circulation, which, in turn, reflects benthonic foraminiferal distribution.

Recent major thrusts in the study of paleoceanography by Srinivasan include studies on the tempos and modes of paleoceanographic change over time scales ranging from just a few thousand years to those over tens of millions of years. The techniques used involve the utilization of marine microfossils, stable isotopes and marine sediments. This research is aimed at understanding as to how ocean climate, circulation and fertility have changed through time.

In the coming years, Srinivasan and his

coworkers propose to focus their efforts primarily on the Miocene, a time of major ice build-up on the Antarctica and one of the major steps in oceanic and climatic evolution. This study would provide a better understanding of the evolutionary steps by reconstructing the oceanography of the relatively stable time just preceding and just following the middle Miocene ice-cap build-up on the Antarctica, and by tracing the oceanographic changes from one time slice, or evolutionary stage, through the next by studying several detailed time-series.

Recently, intensive studies have been undertaken to look closely at two time slice intervals in the Early Miocene. The youngest interval apparently represents an extremely warm time just prior to glacial build-up on the Antarctica. The earlier interval was somewhat cooler than the later one, and is noted for its low variability in both faunal composition and oxygen isotopes. Biostratigraphic and isotopic data are now being compiled for these intervals.

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R N Sukheswala

The Deccan lavas occupy an area of about 512000 sq km in parts of Western and Central India, and there are few equals to this stupendous volcanic activity in other parts of the world. This vast geological province remained unworked, except for a few pioneering attempts in the early part of this century.

It is now almost a recognized fact that during the early geological period, the Earth was divided into two parts—the northern hemisphere called Laurasia, and the southern hemisphere termed the Gondwanaland. The present bi-partisan global configuration is roughly east-west. The sub-continent of India, Africa, South America, Antarctica and Australia in the distant geological past formed one whole continent of Gondwanaland. With the passage of time, the Gondwanaland began breaking up, giving rise to the belief that the positions of the present day continents is due to the breakup and drift of its dissected parts. The mountain-building process and the location of volcano-earthquake belts in specific areas are considered the results of collision of two plates (drifting continents). The Earth globe is now believed to contain six major plates with many more subsidiary plates. The recognition of the boundaries of the moving plates has helped geologists to locate the volcano-earthquake belts of the world, and the belts of economic mineral ore deposits and their origin. It is in such context, and much more, that the present day geologist applies his mind in the study of the volcanic provinces of the world, including the Deccan Traps of India (Lats. 16 and 25 N; Longs. 67 and 82 E).

"The Indian plate seems to bear an imprint of lithospheric breakup of Gondwanaland and magma genesis related to mantle along the present passive west coast. It offers an opportunity to analyse the tectonic framework for within-plate volcanism and its possible control in terms of plate migration. Chemical and isotopic data for the Deccan volcanics would be used for evaluating theories explaining the chemistry of the mantle-derived rocks, open-system processes involving contamination, mixing of magmas and mantle metasomatism. Finally, these findings may contribute towards an understanding of the evolution of the province as a whole in space and time".

"Recent detailed geochemical work has already demonstrated that the voluminous Deccan plateau basalt sequences bear distinct fingerprints of various processes in magma chambers. Therefore, the study of the Deccan Traps rocks may help resolve some of the outstanding ambiguities by the search for systematic criteria by which crustal contamination and mantle

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heterogeneity can be distinguished, if possible" (Subbarao, 1984).

The contribution to the study of the Deccan Traps made by the staff and students of the Geology Department of St. Xavier's College, Bombay, with Sukheswala's active participation and involvement is brought out in this account. The following areas were worked in detail to understand the geology to get an insight into their genesis. (The results obtained proved to be quite interesting and of significance in the understanding of the magma character, and led to the discovery of a new rock type—the carbonatite-alkaline group of rocks—for the first time in India.):

(i) The Bombay area, including Greater Bombay and beyond north a part of the mainland, Maharashtra State.

(ii) The Chhota Udaipur area, Baroda District, Gujarat State.

Bombay Area

The present Greater Bombay (islands of Bombay, Trombay, Salsette, and a group of small islands lying in the Bombay Harbour) area has offered an unique geology. The first attempt to study the island geology was made in about 1850. After that not much attention was paid by the geologists to study these island rocks.

During a span of a decade or so (1960-1970), sufficient data were made available by Sukheswala and his colleagues in the form of seven published research papers. The data revealed that the geology of Bombay is not only complex and challenging, but also totally different from the geology of the adjacent mainland. The following were the major contributions: (i) a detailed geological map was prepared; (ii) the area was established as a focus of central type of volcanic activity as opposed to fissure type of eruptions normally ascribed to the Deccan volcanic province as a whole; and (iii) the lavas (basic and acid) have been shown to have erupted under water. This sub-aqueous eruption of lavas may be taken as a unique feature in the geological history of the Deccan lavas which are mainly of subaerial origin. The sub-aqueous eruptions resulted in the formation of extensive hyaloclastite deposits, which in later stages got interstratified with local fresh water deposits, termed the intertrappeans of Bombay-Salsette islands. They yielded fossils of frog, tortoise, plants (unidentifiable) and fossil fish and fish tooth.

The finding of subaqueous nature of the lavas prompted us to extend our work further north along the coastal margin of the mainland with a major objective to understand and trace the extent of such subaqueous lavas along the western continental margin. Our search revealed that such a situation had occurred with the lavas erupting in the Tertiary Sea along the Tapti Narmada Valley.

As a result of subaqueous eruption of the basaltic lavas, they underwent physico-chemico-mineralogical changes, forming a rock type known as spilite. The origin and the formation of this rock have been described in a paper[12]. The Bhoiwada section described in this paper is a unique example of spilite preserving its ancestry, the original basalt which gradually turns into a spilite.

The Bhoiwada area has also become a classic ground for the study of 'pillow lavas' and hyaloclastities, perhaps the only area known so far in the vast and extensive terrain of Deccan volcanics. This area also provided for the first time a well documented evidence for demonstrating the mobility of REE elements and opened up a challenging task to geochemists the world over.

One paper[2] gives a summary of field relations of Deccan rocks on three islands in the Bombay area, and provides new petrographic and chemical data. Also included is a review of chemical data on the Deccan Province gathered from the literature. The conclusions drawn from the chemical data are: (i) most of the Deccan basalts are found to be late middle stage basalts; (ii) the magma is of tholeiitic nature; (iii) the Deccan province shows an initial stage of iron enrichment, followed by dominant alkali enrichment; (iv) the average Deccan basalt has somewhat more FeO and less Al_2O_3 and MgO than most tholeiitic basalts; and (v) the absence or scarcity of pigeonite in Deccan basalts is attributed to the chemical characteristics of the magma and a rapid cooling with incomplete crystallization of the basalts.

In the Bombay area, the felsic rocks are associated with the basalts. They are believed to represent differentiates of the basaltic magma, produced by crystal fractionation and diffusion of volatiles. Magmatic differentiation was directed initially towards a rhyodacite residuum and only in the final stages towards rhyolitic melts with more K_2O than Na_2O.

The association of mafic and felsic rocks has long puzzled petrologists, especially because rocks of intermediate composition are scarce or absent in most localities. The Bombay area is no exception to this. It is, therefore, also suggested that the felsic magma may have formed by partial melting of crustal rocks during the continued ascent of basaltic magma through the crust. However, the recent Sr and Nd isotopic investigations on these rocks are at variance with this hypothesis, and rather strongly indicate fractional crystallization of basaltic magma (Hawkesworth, Lightfoot and Sethna, 1984). This view is further strengthened by a recent observation of Sukheswala.

The average Upper Deccan basalt closely resembles the average Deccan dolerite. This may suggest that the main intrusive phase of Deccan magmatic activity came after the main effusive phase. Of the two important characteristics of the Bombay geology, one is the occurrence of alkaline rocks in the midst of tholeiites, which is quite unusual. The tholeiite basalts are cut by minor dykes of alkaline rocks, viz., monchiquite, camptonite and nepheline syenite. Such associations are not very common, but are difficult to explain. The other aspect is the find of assimilation diorite in the Bassein area. Indications of mixing of magmas (basic and acid) and/or liquid immiscibility in the Bombay and Salsette islands are on record.

Carbonatite Alkalic Province of Chhota Udaipur

The carbonatite-alkalic province of Chhota Udaipur in Baroda District forms an integral part of the Deccan Traps. The carbonatite-alkalic rocks were discovered for the first time in Amba Dongar and the surrounding foothills, about 23 miles south of Chhota Udaipur (Lats. 21° 52′ 30″ N; Longs. 74° 4′ 34″ E). The carbonatite is part of a ring complex (4 miles in diameter) of alkaline rocks that has intruded into Cretaceous sandstones and limestones

(Bagh beds) and has domed and albitized overlying Deccan basalts.

The centre of the complex is marked by the dome of basalts, dropping down along a ring fault. A cone sheet of carbonatite that flanks this sunken cap is surrounded by an annular body of various nepheline-aegirine rocks (largely ijolite, some with melanite).

The outermost unit at the southern side is a breccia in which fragments of foliated sovite, of sandstone and of basalt, are set in a matrix of nepheline-aegirine-orthoclase-calcite rock. The complex is cut by lamprophyric and other alkaline dykes. Exterior to the complex are four large parallel breccia dykes consisting of an ijolitic matrix and fragments of aegirine-sovite, pyroxenite, Bagh sediments and basalt. These strike north of east, parallel with the trend of the Narmada River, which lies just south of the complex and follows the trend of a major fault.

The body is an unusually fine example of a carbonatite cone sheet ring complex intruded under a hypabyssal environment.

The Panwad-Kawant area to the northwest and adjoining Amba Dongar exposes a major dyke cluster mainly of carbonatite-alkalic rocks. The trappean flows of the area are identified as plagioclase-calcite rocks. They are cut by dykes of alkaline rocks, carbonatites and dolerites. The alkaline group includes a variety of rock types—phonolite, tinguaite, nepheline syenite, lampropyre and ijolite. Plugs of dolerite and alkaline rocks are also observed. One of these plugs of phonolite at Tawa village has locally lifted up Bagh sediments in quaquaversal fashion. The pseudoleucite tinguaite of Ghori is a rock of rare occurrence, discovered for the first time in India. Individual phenocrysts of pseudoleucite in tinguaite measure 2 in and more in diameter. Barring the mafics, the groundmass of the rock is mineralogically almost identical with that of the pseudoleucite.

Our study of the Panwad-Kawant and the adjoining areas revealed that it is a tectonically disturbed zone, riddled with a number of dykes and quite a few faults. The fracture zones seem to exist, one ENE along the Heran River bed parallel to the strike of the Baghs, and the other NW-SE following the river Kara conforming to the strike of the metamorphics. The major and minor intrusions and dykes follow these fault patterns. From Narmada northwards, regular step-faulting seems to have occurred with downthrow to the north. In the Amba Donar region, the drainage pattern is radial originating from Amba Dongar dome. The dome character is the result of forceful injection of carbonatite-alkalic magma, as evidenced in the quaquaversal dips of the Baghs in Amba Dongar.

In the Siriwasan area (adjacent to Amba Dongar), the carbonatite-alkalic magma is injected into the Bagh sandstones mainly along the stratification planes. As a result, the fractured sandstones formed carbonatite breccia. The major constituents of the breccia are quartz, felspar, aegirine-augite, apatite, melanite, sphene, pyrochlor and phlogopite embedded in calcareous matrix.

The Amba Dongar and surroundings present a fine example of fenitisation of sandstones, a phenomenon very common in other carbonatite-alkalic areas as well. Both potash and soda fenitisation are encountered. Though there is a difference of opinion regarding the source of fenitising solutions, i.e. whether they are derived from the silicate or the carbonate fraction of the magma, our work has convinced us that perhaps both the immiscible fractions of the magma, silicate and carbonate were responsible for the fenitisation of the country rocks.

The area is also known for fluorite mineralization. Fluorite is widely disseminated in the later ankeritic carbonatite plugs. The main economic concentrations are located near these plugs and in the boundary zone between the sovite and the Bagh sandstones. They are in the form of veins and cavity-fillings of fairly pure fluorite, and appear to be of hydrothermal origin.

Although in time and space the carbonatite eruption can be seen as an episode in the Deccan volcanism, the carbonatite magma was clearly very different from the widespread basaltic magmas of the Deccan Traps.

Layered Gabbro of Phenai Mata Igneous Complex

Phenai Mata hill (Lat. 22° 8′ N; Long 73° 55′ E), a remnant of a composite plug filled with basalt, gabbro, granophyre and nepheline syenite of successively younger age, is situated in the NW of Amba Dongar. This igneous complex is intrusive into the pre-Cambrian rocks overlain unconformably by Bagh sediments of Cretaceous age. The overlying Deccan Trap flows are seen about six miles south of Phenai Mata hill.

The gabbro body, 2000 ft wide at the base, is marked by rhythmic layering formed by repetitious layers in which alternative minerals predominate. At the base, the rock, practically monomineralic with 90% of plagioclase, is termed anorthosite. Within the anorthosite zone is seen the type of layering described as 'inchscale layering' by Hess. Above the anorthosite zone, the rock is relatively enriched in augite. This pyroxene-rich gabbro is described as a plagioclase heteradcumulate. The gabbro also shows cryptic layering as produced by progressive changes in mineral composition. The major mineral constituents of the gabbro are plagioclase and augite with varying amounts of hypersthene and olivine. From field, chemical and optical data it is clear that differentiation in the gabbro body occurred *in situ* after its emplacement in its present environment. Fractional crystallization, aided partly by gravity and diffusion, seems to have played a dominant role in the process of differentiation. The available literature shows that such rocks have not been described from India earlier.

In this complex, there are encountered in association with basalt, dolerite and layered gabbro, both oversaturated and undersaturated varieties of rock types, viz., granophyre, microgranite, alkali-syenite, etc. The chemistry of the basic rocks indicates tholeiitic character of the magma, which can be considered as the parent magma of the complex. Slow cooling of the layered gabbro produced a residual melt of granitic composition, which, in effect, gave rise to the acid differentiates, the large intrusive masses and dykes in the basic rocks.

The intermediate rock types are also thought to be related to the tholeiitic parental magma. Rapid cooling of the basic magma led to the formation of an iron-rich felspathic mesostasis. This residue, more syenitic in composition, is found as interstitial patches and microaplitic veinlets in some basalts. The remelting of the syenitic mesostasis in the basalts, caused by subsequent intrusive activity, formed the syenitic magma from which the intermediate saturated rock types crystallized as long as the oxygen partial pressure was sufficiently high. With decrease in the oxygen partial pressure, barkevikite crystallized instead of iron oxides. The resulting deficit of SiO_2 is responsible for the formation of the undersaturated rock types.

Some Thoughts for Future Work

The study of the Trap rocks in the two areas of Bombay and Chhota Udaipur has brought to light some new aspects of Trap geology, but at the same time has raised problems which need to be probed into in some detail. The Bombay area is known for the association of acid rocks with tholeiite basalts. Earlier workers have claimed that the origin of the acid rocks may be the result of fractional crystallization of the parent tholeiite basalt; or the acid rocks may be the result of an independent magma, quite unrelated to the tholeiites of the area. Evidence is gathering towards the belief that the formation of the acid magma could have occurred by partial fusion of the underlying basaltic crust, or by fusion of the crust during the uprise of the basalt magma. Positive evidence on either side is lacking. Sr, Nd studies indicate fractional crystallization.

A new interesting aspect of the Bombay basalts is the find of spilite and hyaloclastites, suggeting subaqueous eruption of the lavas. Later search revealed the presence of such rocks at quite a few places along the western coastal margin north of Bombay as far as Baroda. It is likely that a detailed mapping along the western coastal margin may establish a zone of spilite (subaqueous basalts). In such an event, it may be surmised that the basalts which erupted under sea waters may form a constituent part of the Cambay basin, which is an oil-bearing horizon. The work by ONGC geologists may throw some light on this.

The presence of some small alkaline dykes cutting tholeiite basalts of the Bombay area is quite unusual. No effort has been made to explain the origin of these dyke rocks.

The discovery of the Chhota Udaipur carbonatite-alkalic complex has encouraged geologists to find and study such areas in other parts of India. Many such areas have been located since, mainly in the pre-Cambrian terrain of south India. The Chhota Udaipur alkalic province is within the Deccan Traps. In both these situations, economic mineral deposits have been found. More effort should be put in to study these areas to understand the tectonic framework and its relation to the existing mineral deposits. Recent find of sporadic diamonds in the kimberlite pipe of south India is interesting and instructive.

In a review paper[16], Sukheswala has come to the conclusion that the chemical/petrographic data used by earlier workers are at variance with the 'crystallization differentiation' hypothesis model proposed to account for the formation of different rock types identified in the complex. He has proposed the 'fenitisation' model, which can better explain the origin of varied rock types. The proposed 'fenitisation' model needs to be tested with detailed field and laboratory data.

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Profiles in Scientific Research : Contributions of the Fellows, Vol. 1 (Indian National Science Academy, New Delhi), 1986.

K S Valdiya

Confining his activities to the Kumaun Himalaya, sprawling 300 km between the borders of Nepal and Himachal Pradesh, Valdiya has endeavoured to untangle stratigraphic and structural complexities of this very crucial and responsive ventral sector of the Himalayan arc. These studies embrace stratigraphical[1], sedimentological, petrological, structural and environmental aspects and have helped reconstruction of the geological history of the whole Himalayan realm.

Stratigraphic Order and Pattern

The first ever systematic studies of algal stromatolites in India initiating a new line of investigation helped to fix the positions in the stratigraphic ladder of the unfossiliferous carbonate formations[2] of the Lesser Himalaya—Deoban and Shali—and the Bindhyachal (Semri and Bhander)[3]. What was previously regarded as Permo-Triassic (270-180 m.y.) in age was pushed down to the Riphean times (1300-900 m.y.)—a deduction that has been amply substantiated by recent radiometric dating of the associated rocks. Detailed lithological and petrological studies of the chain of lentiform deposits of crystalline magnesite associated with the stromatolite-bearing dolomites of the Deoban formation indicated their synsedimentary replacement origin, the algae playing a very significant role in creating environment conducive to critical concentration of magnesium[4].

The carbonate formation (Deoban) overlies a great group (Damtha) of sandstones-shales alternation. The lower part of this group (Simla-Chakrata formations) is constituted of greywackes and shales of turbidite origin. Comprehensive sedimentological study of the Precambrian Simla-Chakrata flysch of Himachal and Garhwal regions embracing first-ever palaeoccurrent investigation in the Himalaya showed prevalence of turbidity currents, and demonstrated very strikingly that the source of the Lesser Himalayan Precambrian sediments lay to the south in the Aravali domain, and that the palaeoslope of northern India in that period was northwards[5], thus emphatically indicating the geological unity of the Peninsular India and Lesser Himalaya. Latest palaeoccurrent studies show that the pattern remained the same throughout the Palaeozoic period right up to the Tal times[6]. The emplacement of diamictite associated with the flysch is attributed to submarine slides in turbidity-currents environment[6].

The sedimentary formations are covered by uprooted and greatly displaced sheets of metamorphics—intruded by granites—the lower Ramgarh nappe characterized by epimetamorphics with porphyroids and

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the upper Almora nappe of mesograde metasediments with syntectonic trondhjemitic suite of tonalite-granodiorite-granite emplaced into presumably moist sediments during the main phase of tectonic deformation and the leucocratic adamellite and aplite coming a little later towards the end of the protracted period of emplacement[7].

Radiometric dating (of more than 75 samples) carried out by Valdiya in collaboration with J R Trivedi and K Gopalan has shown the whole-rocks age of the granodioritic plutons in the Almora Nappe to be approximately 550 m.y. and the age of the porphyroids of the Ramgarh Nappe and equivalent klippen 1800 m.y.[8].

Structural Set-up and Tectonics

Redefining the nature of the two most crucial boundary thrusts delimiting the Lesser Himalayan domain—the Main Boundary Thrust and the Main Central Thrust—Valdiya[9,10] demonstrated that these thrusts of intracrustal dimension are integrally related with complex and confounding schuppen structures—duplex zones—of imbricated lithotectonic sheets characterized by extreme mylonitization and deformation of rocks, and that they are seismically and tectonically very active. The Main Central Thrust is recognized as an intraplate subduction boundary which played a crucial role in the elevation and development of the Great Himalaya and in fashioning the structural architecture of the Lesser Himalaya. The MCT is defined as a haital metamorphic discontinuity—as the plane marking an abrupt change in the style and orientation of structures and the grade of metamorphism from greenschist facies to the upper amphibolite-lower granulite facies (T 600-650°C, P 5 Kb) of the Lesser Himalaya[10-12].

The outer Lesser Himalayan belt has been demonstrated as riven with not only transverse tear faults[13], but also longitudinal faults of great depth developed along crestal planes in the central part of the synclinorial Krol Nappe. These deep faults have brought up the sedimentary basement in tectonic windows, and differentiated the outer Lesser Himalayan Krol belt into two parts—the southern comprising full succession of the (?) Palaeozoic formations, and the northern part having only the older half of the sequence. Evidence for synsedimentation upwarping of the floor of the Krol basin related presumably to the Calenonian epeirogenic phase has been adduced[2,6,11].

It is demonstrated that crustal accommodation consequent on convergence of the Indian plate with the Asian is taking place by differential movements along these transverse faults[9].

The Ramgarh Nappe, the root of which is involved in complicated duplex structure under the Main Central Thrust, is interpreted as the overthrust prolongation of the argilloarenaceous upper part of the Damtha Group of the sedimentary succession of the autochthon. The deeper part of this unit, with porphyritic granite basement involved in tight folding, overturning and multiple splitting along axial planes, was thrust southwards along with the basement granitic rocks to give rise to the Ramgarh nappe and its analogues[14].

State of the Natural Environment

Recent work of Valdiya[15] relates tc deterioration of land resulting from landslides and mass movements. In ar attempt at mountain-hazard zoning, twc major vulnerable (seismically active structurally weak and ecologically sensitive) belts have been delineated—one along the boundary of the Siwalik and the Lesser Himalaya and the other in the zone of the Main Central Thrust. Identifying indiscriminate road construction, overgrazing on hill slopes, and absence of proper drainage in inhabited areas as the principal causes of hillside instability and resultant mass movements, a strategy for management of hazard zones and mitigation of landslide hazards has been proposed.

Future Direction of Research

The fundamental aspects of geodynamics of the boundary thrusts delimiting the Lesser Himalaya, with special emphasis on inter-relationship with tectonism (including neotectonic activities)[10,16], and various earth processes and their bearing on the evolution of this mobile belt, will be the principal field of studies.

Investigation of the causes of various environmental stresses the land of Kumaun is experiencing, the implication of mismanagement of varied earth resources and areas of geological hazards will be continued, with the primary objective of mitigating the stresses and hazards resulting from environmental imbalance.

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V V R Varadachari

Varadachari, a leading physical oceanographer of India, has been responsible for formulating research programmes and organizing cruise programmes in the field of physical oceanography in India since the International Indian Ocean Expedition (1962-65). Right from the inception of the National Institute of Oceanography (NIO), on 1 January 1966, he has been organizing studies in physical oceanography, as the Head of the Physical Oceanography Division of NIO and later as its Director.

His main contributions are in the areas of upwelling, ocean currents, watermasses, submarine canyons, coastal zone management and the impact of oceans on the Indian south-west monsoon. He employed some new techniques, such as vertical time sections, etc., for studies on upwelling and sinking, and studied the physical and dynamical aspects of upwelling along the Indian coastline. He developed a new theory on coastal upwelling, stressing the role of coastal currents as a factor in inducing upwelling[1]. The theory has been found useful in explaining upwelling not only along the Indian coastline but also along the other coasts in the Indian Ocean region, such as the Somali Coast. He has studied the vergence field in the North Indian Ocean in order to locate the upwelling and sinking regions in the area in different seasons[2]. He has also studied the surface circulation in the North Indian Ocean[3,4]. He identified and surveyed the watermasses of the Red Sea and the Persian Gulf origin in the Bay of Bengal[5]. Several submarine canyons off the east coast of India were located and surveyed by him[6]. His studies on the thermal structure in the Arabian Sea have contributed to an understanding of the dynamics of the Southwest monsoon[7].

The other area in which Varadachari has done significant work is coastal zone management. Beach erosion problems along the Indian coastline have been studied, particularly along the coasts of Kerala and Goa. Beach evolution was studied in response to waves, tides, winds, currents, etc.[8-11]. Problems of sedimentation in harbours, rip currents off beaches, formation of sand bars near river mouths and formation of mud banks in the nearshore regions were investigated[12-15]. Under his Directorship (1981-1985), NIO made significant contributions in the field of marine science. It played a key role in organizing the first, second, third and fourth Indian Scientific Expeditions to the Antarctica, in 1981, 1982, 1983 and 1984 respectively. India has received the status of 'Pioneer Investor' in the Survey of 'polymetallic nodules' in the Indian Ocean, based on the work carried out by NIO, mainly during his Directorship. NIO has rendered services to several governmental

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and industrial agencies in the country in the vital fields of development of ports and harbours and offshore oilfields, effluent disposal, development and protection of coastal zone, etc.

Varadachari, as Vice-Chairman of the Committee on Climatic Changes and the Ocean (CCCO) of the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC), contributed to the planning and formulation of the global experiments, such as the Tropical Ocean and the Global Atmosphere Programme (TOGA) and the World Ocean Circulation Experiments (WOCE).

He has initiated at NIO programmes of research in the areas of application of remote sensing to oceans, oceanic modelling, etc., with the aim of developing facilities for the prediction of marine environment and climatic changes. Some of the other major areas of ocean research which were initiated or which received impetus under his Directorship of NIO are minerals from the sea, food from the sea, organic chemicals from the sea, energy from the sea, deep sea biology, study of the Antarctic Ocean, etc.

Varadachari, who started his career as a teacher at postgraduate level in Meteorology and Oceanography at the Andhra University, in 1949, also made significant contributions to teaching and formulation of marine science programmes in several Indian universities having postgraduate courses in physical oceanography and meteorology.

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M N Viswanathiah*

Among the several Proterozoic sedimentary basins of India, the Cuddapahs and the Kurnools are well known through the work of several geoscientists, whereas the Kaladgis was almost a neglected basin, although the pioneering contribution of Robert Bruce Foote (1876) was on record. It was Viswanathiah who paid special attention to this basin and made significant contributions on its stratigraphical, structural, sedimentological and palynological aspects.

In 1968, a new post-Kaladgi stratigraphical unit, named Badami Group, was proposed for the first time after a systematic study of the Kaladgi basin covering an area of over 5100 sq km in Dharwar, Bijapur and Belgaum Districts of Karnataka[1]. The recognition of this new group of sediments has helped in tracing the complicated structural unconformity existing between the Kaladgi and the Badami Groups and also in establishing a new lithostratigraphical regional classification in accordance with the American Code of Stratigraphic Nomenclature, based on detailed field data and measurement of several stratigraphic sections where the lithofacies are typical[2].

It was further shown that the Kaladgi sediments, which are 1400 m thick exposed in a WNW-ESE oriented synform, rest unconformably on the older metasediments and igneous intrusives, while the Badami sediments which are 300 m thick, consisting of almost horizontally bedded clastics and limited carbonates and argillites, rest with a clearcut unconformity on the steeply dipping clastics and carbonates of the Kaladgi Group.

Distinct authigenesis of several heavy minerals like tourmaline, zircon, sericite and feldspars in the Kaladgi sediments which developed due to incipient metamorphic processes was identified for the first time[3]. A number of stromatolitic bioherns[4] reported for the first time are of great value not only in biostratigraphic classification of the Kaladgis but also in the correlation of the Kaladgis with other sedimentary basins.

The rocks of the Kaladgi and the Badami Groups were considered to be totally unfossiliferous and not useful for any correlatory purposes. But detailed palynological probe of the entire stratigraphic succession has yielded very rich microbiotic occurrences, which are of far-reaching significance in unravelling the age of the sedimentary rocks in the absence of reliable geochronological data. The acritarchous and microorganic remains obtained from each of the different formations are very characteristic and have thrown much light on their

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possible stratigraphic age[5,6]. The Kaladgi sediments have yielded significant microbiota, which can be assigned to Cambrian period, approximately ranging in age from 1600 to 500 my (Lower Ripean to Upper Cambrian).

Similarly, the Badami Group has yielded valuable data of fundamental significance having no commonness either quantitatively or qualitatively. The acritarchous forms are known to characterize typically the Ordovician rocks comparable to one or the other region of the world. For example, *Leiosphaeridia aptiana* confines itself to Ordovician rocks of N. Germany (Eisenack, 1974) and *Leiovalia elongata* has an exclusive association with the Ordovician rocks of Nobolska horizon, Russian Platform (Umnova, 1975).

The other small but typical microbiotic association is constituted by an assemblage of Scolecodonts, particularly *Aniocerasites* sp. and *Nareidavus cf. elleri*, which are found exclusively in Ordovician of Montagne Noire, France. Equally important is another association of Chitinozoans represented by taxa like *Desmochitina minor typica* confined to Ordovician of Port Peninsula, Western Newfoundland, Canada. The Scolecodonts and Chitinozoans, which are reported for the first time from India and are so abundant and characteristic in the Badami Group, are absolutely unknown in the underlying rocks of the Kaladgi Group. Thus, the Badamis are referable exclusively to Ordovician ranging in age from 500 to 430 my[7,8].

These factors related to microfloral diversity, assemblage variance, differences in individual taxa, evolutionary aspects and degree of preservation clearly brought out for the first time that the Badami Group bears an independent identity different in age from the underlying Kaḷadgi Group. Nevertheless, further work on the Badami Group of rocks occurring around Nesari, Ajara and Phonda of Ratnagiri District of Maharashtra is progressing fast. The Rb-Sr method of dating representative samples of the critical lithologic units of both the Kaladgi and the Badami Groups based on wavelength-dispersive X-ray fluorescence spectrometry (WDXRFS) is being used to corroborate the age indicated by the palynofossils. Simultaneously, the major-, minor-, and trace-element geochemistry of the argillites, quartzarenites and dolomites of these groups is being studied.

Similar palynological studies extended to the Cuddapah Super Group have resulted in the discovery of important microbiotas hitherto unknown[9], which are assignable to ages beyond Cambrian. Further, for the first time in India, undoubted microstructures have been reported from the Sargur Schists (Precambrians) near Mysore[10], which are supposed to be the oldest rocks in Peninsular India.

Viswanathiah was largely responsible for the starting of the journal *Indian Mineralogist* (organ of the Mineralogical Society of India). He has been the Editor of this journal. To the credit of Viswanathiah again goes the establishment of a separate Mineralogical Institute in the University of Mysore, exclusively for experimental mineralogical research on Hydrothermal Equilibria of Rare Earths[11–13] and for Hydrothermal Growth of Crystals[14,15]. While engaged on mineralogical studies, Viswanathiah also paid attention to copper mineralization, with particular reference to Karnataka[16–18].

On the whole, starting from scratch in 1961, the Geology Department of the University of Mysore has now become an active centre of research in earth sciences due largely to the sustained efforts of Viswanathiah.

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W D West

During his service in the Geological Survey of India, which began in 1923, West made contributions to the geology of India in three main fields: Stratigraphy and structure of the Archaean rocks in the Nagpur district; structure and correlation of the rocks in the Simla Hills; and petrology of the Deccan Trap volcanic rocks.

Detailed mapping of the Sausar Series of rocks in the Nagpur and Chhindwara districts, begun by L L Fermor before the first world war, was taken up by West in the Nagpur district in 1924. A study of the structure of these highly metamorphosed argillaceous, arenaceous, calcareous and dolomitic rocks led to the recognition of *nappe* structure for the first time in the ancient schistose rocks of India[1]. An account of the development of West's ideas regarding the geology of this tract was given by Fermor [*Mem Geol Surv India*, **70** (Pt 2) (2) (1940) 274-85].

West worked in the Nagpur district in the winter months, and spent the summer months in the geological survey of the Simla Hills. For a long time, little work had been done on the geology of the Himalaya. It was restarted in 1925, when G E Pilgrim and W D West began a survey in the Simla-Chaur area. The problem was to account for the superposition of metamorphosed rocks, including granite, over unmetamorphosed rocks, a problem left unsolved by H B Medlicott in 1864. Pilgrim and West suggested the presence of large scale overthrusts and recumbent folds. Their memoir, published in 1928, has since been reprinted[2]. Though some of the conclusions then reached may have to be modified, this was the first attempt made to give a modern interpretation to the structure of the Himalaya. Later, West investigated the geology of the Shali area, north-east of Simla, where the Sutlej river has cut deeply through the rocks of the Chail Series, revealing younger rocks, including fossiliferous Tertiary rocks, lying beneath the Shali (Chail) thrust[3].

Another line of work, which was later to become of special interest to West, was started in 1925, when he visited the Ahmedabad district and Kathiawar to examine the cores of Deccan Trap obtained from a number of deep borings. This led to the publication of a comprehensive paper in which he discussed the origin of the basic picrite-basalt flows that were later to be the subject of discussion by petrologists studying the flood eruptions in other countries, while he also recognized that the parental magma of the Deccan Traps was of tholeiitic type[4].

In 1935, Quetta was rocked by a severe earthquake in which 25,000 people lost

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their lives. West studied the effects of the earthquake and its possible origin, suggesting that the concentration of earthquakes in this sharp re-entrant angle in the alignment of the mountains was due to an underground tongue of peninsular India obstructing the forward advance of the Tertiary fold towards the south-east[5]. This was followed by his presidential address to the Section of Geology and Geography, Indian Science Congress in 1937 on 'Earthquakes in India'[6].

In 1940-42, West led a party to Afghanistan to search for coal in the Jurassic Saighan Series of rocks north of the Hindu Kush. The party was successful in proving considerable reserves of coal in the region of Darra-i-Suf[7].

After joining Saugar University in 1955, West found himself located on the Deccan Trap, and his interest in these rocks was revived. A paper on the source of the Deccan Trap flows, based on a study of the Deccan Trap around Sagar, was published in 1959[8]. In this, he concluded that the lava flows had travelled many miles, and he discussed the problem of locating the vents up which the lava had been erupted, particularly in areas where dykes are absent or scarce. He summarized his views on the origin of the Deccan Trap flows, and on the relationship between the petrography of the flows and the structure of the subcontinent, in his D N Wadia Medal Lecture delivered to the Indian National Science Academy in 1984[9]. In this he made a comparative study of the Deccan Trap with other flood eruptions in South Africa, the North-West USA and the Brito-Arctic region.

At Sagar West also found much to think about regarding the geomorphology of this area of Vindhyan and Deccan Trap rocks, recognizing that peculiarities in the drainage pattern of the area could be explained by assuming that it had arisen on a surface of Deccan Trap, and that on the removal of the latter by erosion it had become superimposed on the underlying pre-Deccan Trap Vindhyan topography[10].

During frequent road journeys from Sagar to Jabalpur, West was impressed by the structural importance of the line of the Narmada valley, and he drew attention to the fact that while to the south of the line no Vindhyans occur, to the north no Gondwanas occur, suggesting that it had for long been a line of weakness, with the areas to the north and south moving up and down relatively to each other along this line[11].

Now in his 86th year, little remains for West to accomplish, except to light the way for the younger generation to become good geologists.

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Periodicals

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